REPORT

ON THE

WATER-SUPPLY OF CERTAIN CITIES

OF

THE UNITED STATES,

COMPILED UNDER THE DIRECTION OF

PROF. W. P. TROWBRIDGE,

CHIEF SPECIAL AGENT IN THE DEPARTMENT OF POWER AND MACHINERY EMPLOYED IN MANUFACTURES,

BY

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LETTER OF TRANSMITTAL.

SCHOOL OF MINES, COLUMBIA COLLEGE,
NEW YORK, *June* 1, 1882.

HON. CHAS. W. SEATON,
Superintendent Tenth Census.

SIR: I have the honor to forward to you the report of Mr. Walter G. Elliot on the water-supply of certain cities and towns of the United States. Under Gen. Francis A. Walker's direction the subject was taken up by the division of the census under my charge, and Mr. Elliot, of this city, was appointed to visit a large number of the principal cities and towns of the country, and to ascertain by personal examinations and inquiries every thing of public interest connected with the water-supply of such towns. His report therefore contains a large amount of valuable information which can not be found elsewhere.

The statistics published in connection with Mr. Elliot's report of towns not mentioned by him were collected by correspondence directly from my office, this work having principally been accomplished by Mr. Fred. N. Owen, of New York, a graduate of the School of Mines, Columbia College, to whom I was indebted for much valuable assistance in the prosecution of the census work intrusted to me by General Walker.

I have the honor to be, very respectfully, your obedient servant,

W. P. TROWBRIDGE,
Chief Special Agent, Tenth Census.

INTRODUCTION.

In a consideration of the water-works of the country and a description thereof, it has been found convenient to group them according to their systems of supply, rather than according either to the population of the cities, or to the magnitude or peculiarities of these systems. For this purpose, therefore, the systems have been classed as follows:

1. Gravity supply;
2. Direct pumping;
3. Pumping to stand-pipe;
4. Pumping through stand-pipe, the surplus above consumption passing to reservoirs;
5. Pumping through stand-pipe to reservoirs;
6. Pumping direct to reservoirs;
7. Pumping by water-power.
8. Combinations.

Nos. 1 and 2 may be considered pure types, and the rest merely modifications of these types; but the distinctions have been used for convenience in reference.

A pure type of each system will be described in the course of this report, and, as a rule, the largest and most complicated of each will be selected as embodying all peculiarities contained in the smaller and simpler ones.

Thus, of the eight systems, we may consider New York and Boston as types of No. 1; Burlington (Iowa) and Indianapolis as types of No. 2; Chicago, Toledo, and Sandusky as types of No. 3; Providence and Memphis as types of No. 4; Nashville as a type of No. 5; Lowell, Pittsburgh, and Cincinnati as types of No. 6; Manchester (New Hampshire) and Bangor as types of No. 7; and Philadelphia as a type of No. 8.

It has been the endeavor, so far as possible, to obtain details of cost of the pure types, in order that a comparison of the original and maintenance costs may be made. Wherever possible to obtain them, photographs of pumping-engines, pump-houses, stand-pipes, drawings, etc., have been added to aid description and to exhibit peculiarities.

Items of interest—facts obtained by observation from civil and mechanical engineers and superintendents of works—are given when they appear trustworthy, and details not obtainable by personal examination, or by personal application to the engineers, have been freely taken from printed reports.

In the different pumping-stations there is an endless variety of engines, with all grades of duty from 15,000,000 to 120,000,000 foot-pounds. Cornish engines, of which there are a considerable number, are usually of a capacity of from 3,000,000 to 10,000,000 gallons per 24 hours; and while, as a general rule, they show high duties, they are invariably very expensive in first cost, and are so cumbersome that it becomes a long and difficult operation to execute repairs. They have been erected less frequently each year.

WATER-PIPES.

With regard to the use of different kinds of water-pipe much can be said *pro* and *con;* but wrought-iron and cement pipes are being gradually replaced by cast iron in towns where they have been used for any great length of time.

It seems to be the verdict of engineers and water-works authorities generally that cast-iron pipes are strongest and most durable, most expensive in first cost, most liable to incrustation save when coated with tar, as in modern practice, most easily laid, tapped, and manipulated, and require least excavation. As to their durability, those which were first used in the country were laid with no coating on the inside, exposing a rough cast surface to the action of water flowing through them for from 20 to 30 years. The result was a rapid formation of tubercles, and consequent reduction of the effective diameter. This has taken place in many instances to such an extent that, in cases which I have seen, a 16-inch pipe has been reduced to 12 inches, and one of the latter diameter to 6 inches. They had been buried ten years. A 24-inch main, which had been coated before laying, in one of the thoroughfares of New York, on being removed in sections after 10 years' use, had this formation to a thickness of 1 inch.

Undoubtedly cases of much greater incrustation have been encountered in different cities, but the above, coming under my observation, will serve as illustrations. On the other hand, cement-lined pipes are cheaper in first cost, the joints are easily made, and their diameter remains undiminished indefinitely. As originally laid, such pipe consisted of a thin shell of sheet iron lined with 1 inch of Portland cement, and jointed together at the ends in a variety of ways. It was afterward laid in the trench and surrounded with cement or concrete. This class rusted badly, and soon wore out. An improvement upon it was an exterior coating similar to the interior. This lasts much longer, but is fragile. Later improvements promise better results. Bored wooden logs are now little used, but have done good service. They are still laid to good purpose in Detroit (*q. v.*), and are the cheapest yet designed. A very common but unscientific practice is the placing of iron gates in cement mains. Incrustation soon diminishes the effective capacity of the pipe to that of the incrusted gates.

FILTERING BASINS.

Filtering basins are those in which the water is allowed to flow freely upon beds such as below described, and, after downward filtration, is collected in a well or chamber at one end. There are but few of these in the country. Where used they are of uniform construction, differing only in shape to conform to peculiarities of topography.

Generally speaking, the water is allowed to percolate through about 4 or 4½ feet of sand and gravel in layers, the lowest being about 12 inches of 4-inch stones, overlaid with 8 inches of smaller stones, and that in turn by from 1 to 2 feet of gravel, the top stratum being from 1 to 2 feet of fine sand. Where most effective these basins are supplied by gravity from some stream, on the banks and below the level of which they are situated. The amount of water filtered in a given time varies greatly with the head of water on their surface, length of time in use, length of time since cleaning, character of organic or mineral matter in suspension, etc. This matter is therefore given as minutely as possible in the report upon each city where filters are in use. They are expensive in construction, and therefore are seldom built of sufficient capacity to be of use for more than a few years at a time, and are a constant source of trouble. The best types may be seen at Burlington, Iowa, and Bangor, Maine. Quite a number have been built and after a short use abandoned, as seen in Toledo, Ohio; Providence, Rhode Island; Columbus, Ohio, and other cities. Lowell, Massachusetts, has a filter of peculiar construction, but of only partial efficiency, owing to small size and rapid fouling.

The greatest difficulty is experienced in the filtration of water bearing much clay in suspension, the operation being so troublesome and expensive as to warrant in many cases the abandonment of such a source of supply. The trouble arises from the fact that it requires much time to settle if first led into subsiding basins. After a brief period it clogs up the interstices in the sand of the filtration basin, or forms an impervious clay coating, all action thereupon ceasing. In Toledo at times the diminution in the quantity of water filtered was so rapid as to be perceptible each day. Aquatic plants seldom prove troublesome in this respect, though always more or less so at the screens of inlet-chambers.

Impounded waters are almost universally troublesome at certain periods, owing to the so-called "fishy" odor and peculiar taste, which seems in no two cases to be ascribed to the same cause. As a rule, it does not appear noticeable in the bodies of water themselves, but develops itself after passage through the pipes on being drawn from the faucets. Trouble from the aquatic plants which appear at certain seasons of the year is usually prevented by changing the depth at which the water is drawn. One of the simplest methods of accomplishing this is by means of the apparatus described under Norwich, Connecticut.

Of infiltration galleries, where water percolating through the surrounding soil is collected into a gallery or tunnel and thence flows to the collecting well at one end, the best type is found at Columbus, Ohio (*q. v.*), where the supply is obtained from a sand and clay soil. Another instance is at Dubuque, Iowa, where water is supplied from crevices in the limestone. Water thus obtained is generally of remarkable purity, although in the case of Dubuque it is hard by reason of the carbonate of lime dissolved out of the neighboring rock.

COMPARISON OF SYSTEMS.

A careful examination of the report will show that the gravity system is most in vogue in the East, where the country is more mountainous and the settlement of earlier date, and the Holly or the stand-pipe system in the West, where the country is level. The gravity system is, as a general rule, operated with less expense than any other, save the Holly system run by water-power; it is usually more expensive in first cost, thereby necessitating a greater amount of annual interest. The increase in cost is due to extra length of conduit required by the remoteness of the source of supply, and in most cases to the cost of a distributing reservoir, for the same reason. There are but few cases in which such a reservoir is dispensed with in a gravity system. The dam is also an expensive necessity. Where water-power is available, the system of direct pumping with a Holly engine seems to be the most economical in every way. Illustrations of this may be cited in the case of Manchester, New Hampshire, and Bangor, Maine, leaving out of consideration the cost of a filtering gallery in the latter instance.

PURITY OF WATERS.

The purest and best drinking waters are those derived from springs in granite, trap-rock, and sandstone formations. Next in order of purity are the impounded waters of small streams, uncontaminated by passage through manufacturing or cultivated districts. These, however, usually contain more organic impurity than the former. Wells properly located in sandy districts furnish a supply free from mineral impurity, and almost wholly without organic contamination.

The supplies derived from rivers, of which system there are probably the largest number of examples, vary from exceeding purity to water almost unfit to drink, as in some cities where the rivers are polluted with sewage, and often are of very bad odor. In such cases it is not unusual for visitors to be affected as soon as they drink of the water. In the case of the Mississippi and Ohio rivers, the mechanical impurities are in such amount as to render the water unfit for use without settling or filtration.

ILLUSTRATIONS.

Many of the illustrations were made from photographs taken upon the spot, and from which the photo-engraved plates were executed.

WATER-SUPPLY OF CITIES.

1.—GRAVITY SUPPLY.

NEW YORK, N. Y.

The city of New York contains 1,206,299 inhabitants, and is located at the confluence of the Hudson and East rivers, the latter being a tidal estuary connecting New York bay with Long Island sound. The main portion of the city is limited on the north by a small tidal stream known as Harlem river, and connecting the East and Hudson rivers at points respectively 7 and 13 miles from the southern extremity, a point known as the Battery.

Topographically, from Canal street ($1\frac{1}{2}$ mile from the Battery) to the lower end, the city slopes each way from a central ridge (Broadway) to the rivers. Canal street, at right angles to Broadway, is in a hollow at nearly tide-level. Above this point to One hundred and twenty-fifth street, $6\frac{1}{2}$ miles, the ground gradually rises to a total height of from 106 to 150 feet above tide-level. Above this the topography is exceedingly irregular, varying from tide-level to 200 feet elevation.

Geologically but two classes of material seem to underlie the city—gneiss rock in most places, and alluvial deposits or sand in the remaining parts.

Water from the Croton system of lakes and ponds was first introduced into the city in 1842. Ineffectual attempts had been made a number of times before to supply the city from wells, ponds, and small creeks within the city. In each case the water had proved insufficient in quantity and poor in quality.

The system in use is a gravity supply derived from a series of small lakes and brooks in Putnam and Westchester counties, at the confluence of which, known as the Croton river, a dam has been constructed, from which a brick and masonry conduit conveys the water about 40 miles into the city. At the crossing of the Harlem river a bridge, known as High bridge, of masonry, with fifteen arches, 50 and 80 feet span, conveys the water over the river through three pipes, two of 36 inches and one of 7 feet $6\frac{1}{2}$ inches diameter. At the southern end of the bridge a set of pumping machinery draws water from the conduit and forces it into a high-service reservoir of small dimensions for the supply of an elevated district about Fort Washington and Washington Heights. From here the masonry conduit continues to Manhattan valley. It crosses the latter along Tenth avenue by means of iron pipes, the greatest depression of which is 105 feet below aqueduct line. There are two 36-inch pipes, one 48-inch pipe, and one 60-inch pipe. They are connected with the aqueduct at each end through masonry gate-chambers.

From about One hundred and seventeenth street to Ninety-second street, iron mains convey the water to gate-houses at the latter point near Ninth avenue. From the gate-houses the water flows through part of the original aqueduct, and also through pipes (details of which could not be accurately ascertained) eastward into the receiving reservoirs in Central park between Fifth and Seventh avenues.

There are two of the latter, one built in 1840 and the other in 1862. The former is now almost useless. From here the water flows through Fifth avenue to a small distributing reservoir of masonry at Forty-second street to Fortieth street; this reservoir is about to be removed on account of its small capacity, it holding less than one-quarter of a day's supply. The Central Park receiving basin will then become the distributing reservoir of the system.

The Croton river has its origin in Putnam county, New York, and is fed by small brooks and lakes on its course to the Hudson river, into which it empties just above Sing Sing, on the east bank of the river, 40 miles above New York. The geological structure of the country through which it flows is of gneiss, mica, slate, and sandstone formations, with a little limestone.

The entire drainage area of the Croton river is calculated from surveys of 1857–'58 at 338.82 square miles, and there are fifteen main ponds and lakes in which the water is gathered or stored; most of them, having had the original proprietors' names attached, are now designated by letters of the alphabet. The following list gives particulars concerning them:

Reservoir.	Area.	Capacity.	Drainage area.	Dam.		Length of reservoir.	Distance from Croton dam.	Elevation.
				Extreme depth.	Extreme length.			
	Acres.	*Gallons.*	*Sq. miles.*	*Feet.*	*Feet.*	*Feet.*	*Miles.*	*Feet.*
A	485.00	5,211,015,625	20.45	64	1,500	12,300	0.50	390
B	192.00	1,701,835,337	15.20	55	1,700	0,000	12.75	500
C	730.00	6,589,101,562	13.71	43	1,700	16,609	14.30	550
D	1,008.00	9,033,632,812	41.95	48	770	21,000	20.25	500
E	303.00	3,360,206,857	20.37	64	700	7,500	23.75	600
F	600.75	6,120,335,937	12.51	21	1,560	10,600	15.50	500
G	452.59	4,861,035,156	20.90	73	541	12,200	18.70	375
H	384.67	2,490,062,500	75.46	40	545	14,748	19.30	375
I	449.00	4,205,820,654	70.52	62	331	12,745	20.45	415
J	101.38	2,314,074,703	11.02	69	1,311	11,616	28.71	500
K	512.74	5,071,449,219	78.90	72	904	14,800	15.21	275
L	262.75	2,328,217,733	26.86	74	757	13,120	10.54	295
M	492.25	4,392,131,445	23.34	72	925	12,300	13.83	316
N	107.00	1,676,049,171	30.96	60	686	8,050	7.71	250
O	230.47	2,182,337,109	17.32	90	1,170	7,020	9.07	305

Of the above list, only two are artificial, that at Boyd's Corners—reservoir E—and that at Middle branch of Croton river—reservoir G; but it is intended eventually to dam all of the outlets from the natural lakes and ponds and convert them into storage reservoirs of greater capacity. The dam at E (Boyd's Corners) is one of the finest and best-constructed masonry dams in this country.

These two dams, built at a cost of $1,510,000, will be described separately. The minimum flow of the Croton river is stated at 27,000,000 gallons per day, and the daily average in dry years varies from 300,000,000 to 367,000,000 gallons. Of this amount, at present only about 100,000,000 gallons (95,000,000 in 1880) passes through the aqueduct for consumption in the city.

The Croton dam, having been first constructed, may appropriately be described here. The chief engineer of the work was John B. Jervis, C. E., with Horatio Allen, C. E., as first assistant.

The dam, which backs up the water for several miles, forming Croton lake with an area of 400 acres, is 434 feet long, 284 feet of which is in masonry and the remainder of earth embankment.

The greater part of the structure rests upon a stratum of alluvial soil containing bowlders, the left bank, however, being granite and gneiss rock.

The piers C and D, of timber, with walls connected by ties, were first constructed and filled in with stone. The top was planked, and upon it the two smaller wooden piers F and G were built and filled in as before. Pier F was planked on top.

The space E was then filled in with concrete, and the tops of F and G were connected by ties of timber. Another pier, H, was then constructed in front of D, the top in front of it being filled in with concrete.

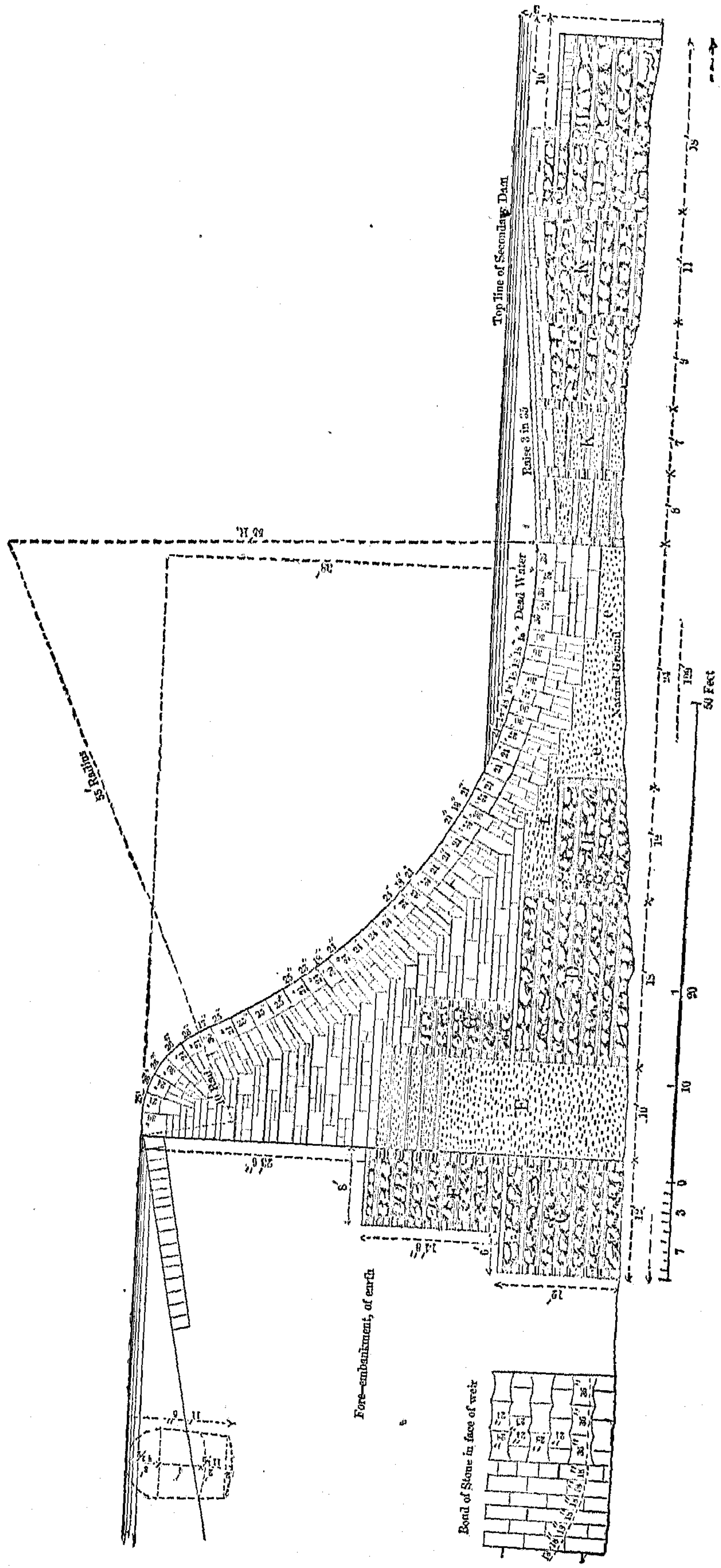
The piers K, K, in four compartments, were put down, two being filled with concrete and two with stone. They were of 12- by 12-inch timber, and the top was covered with a planking laid upon a slope rising 3 feet in 35 feet, as shown in the cut. The front of this "apron" is protected by another pier of timber filled with stone and faced with heavy planking.

Upon the foundations E, D, G, and H, already described, the masonry of the dam was constructed. It was set in hydraulic cement, the main body being laid in horizontal layers, and the facing of finely cut granite blocks bonded together being laid in a reversed curve. At the crest it is convex, and has a radius of 10 feet. This curve at a few feet below the crest tangentially joins the reverse or concave curve built to a radius of 55 feet.

The general objects of this arrangement and of the apron, the details of which are given in the cut, are to break the fall, and, as nearly as possible, to conform to the curve of the overfalling water. The face blocks are from 17 to 24 inches wide and 24 inches deep.

The upstream side of the dam is filled in against the piers and masonry with earth, forming a gentle slope up stream. For a distance of 20 feet from the crest this embankment is paved with granite blocks, laid dry to prevent damage by wave-wash. From the right end of the overfall to the right bank the dam is of earth; details of the construction could not be obtained.

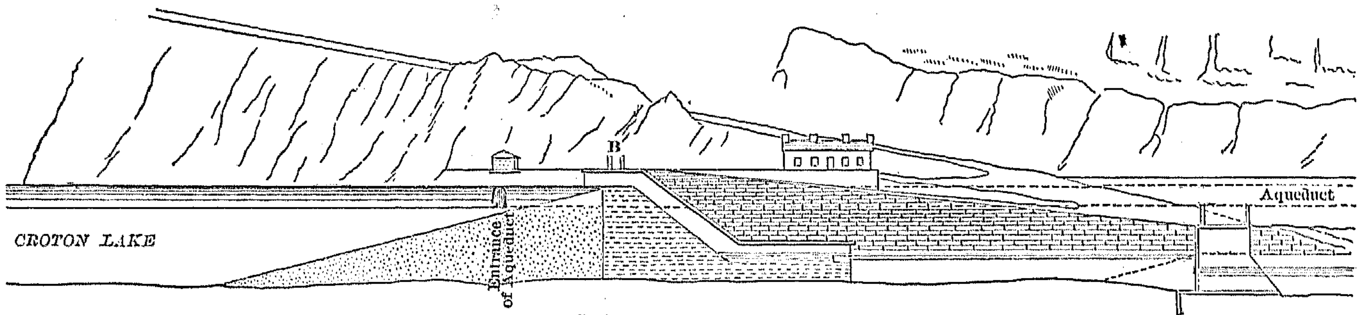
Near the left end of the dam, 90 feet from the river-bank, a waste-culvert is built through the masonry 22 feet below the crest, and closed by two sets of gates operated from within a gate-house 14 feet square, situated on the crest and reached from the river-bank by a foot-bridge.


Top line of Secondary Dam
Raise 3 in 25
Dead Water
Natural Ground
55 Radius
Fore-embankment, of earth
Bond of Stone in face of weir
50 Feet

CROTON DAM.

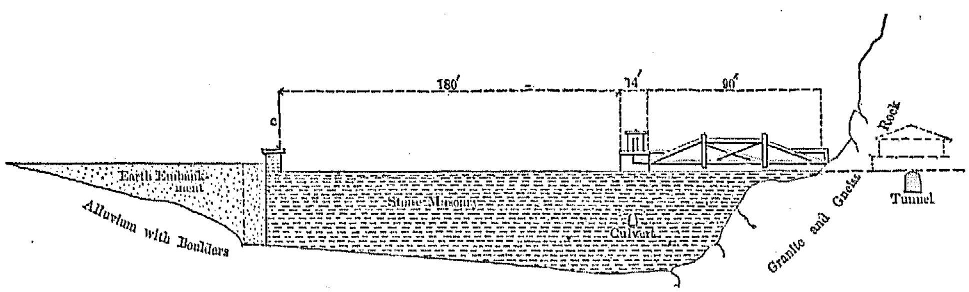
A secondary dam is built 300 feet down stream from the main one. It is of timber filled with stone, and is intended, by backing the water between it and the main dam, to keep the timber piers K and L of the latter always submerged. A waste-weir is built in it near the left shore, arranged so that all the water above it may be drawn down.

The Croton dam elevated the water of the stream 40 feet, making the water-surface 166 feet above mean tide, and containing an available quantity in the Croton lake of 5,000,000,000 gallons.



CROTON AQUEDUCT.

The Croton aqueduct, which conveys the supply to the city, starts from the left bank of the river immediately above the dam, in a tunnel 180 feet long through the rock to the gate-chamber. Throughout this length it is somewhat larger than the rest of the aqueduct.



The large reservoir at Boyd's Corners on the west branch of the Croton, 23 miles above the Croton dam, is formed by a masonry dam constructed in 1870, and which has been the subject of a paper by Mr. James J. R. Croes, civil engineer, before the American Society of Civil Engineers (a). The facts here given concerning it have been almost exclusively derived therefrom.

The dam, as originally designed by George S. Greene, civil engineer, and carried into execution by Mr. Croes as chief engineer, is one of the finest masonry dams in the country.

The reservoir has a water-surface of 279 acres, a maximum depth at the dam of 57 feet, and an average depth of 30 feet.

The capacity is about 2,729,430,000 gallons, and the dam is situated between two lines of hills (which at this point closely approach each other), and at right angles to the valley. The formation beneath the stream here was gneiss, and fine-grained, hard, blue rock, overlaid by pervious, compact, gravelly earth and drift.

The dam was built of masonry for several reasons: (1) The liability of the stream to sudden and heavy freshets, which would have destroyed a half-finished earthern dam; (2) there were no suitable materials for puddling at hand; (3) good quality and large quantities of building-stone were close at hand.

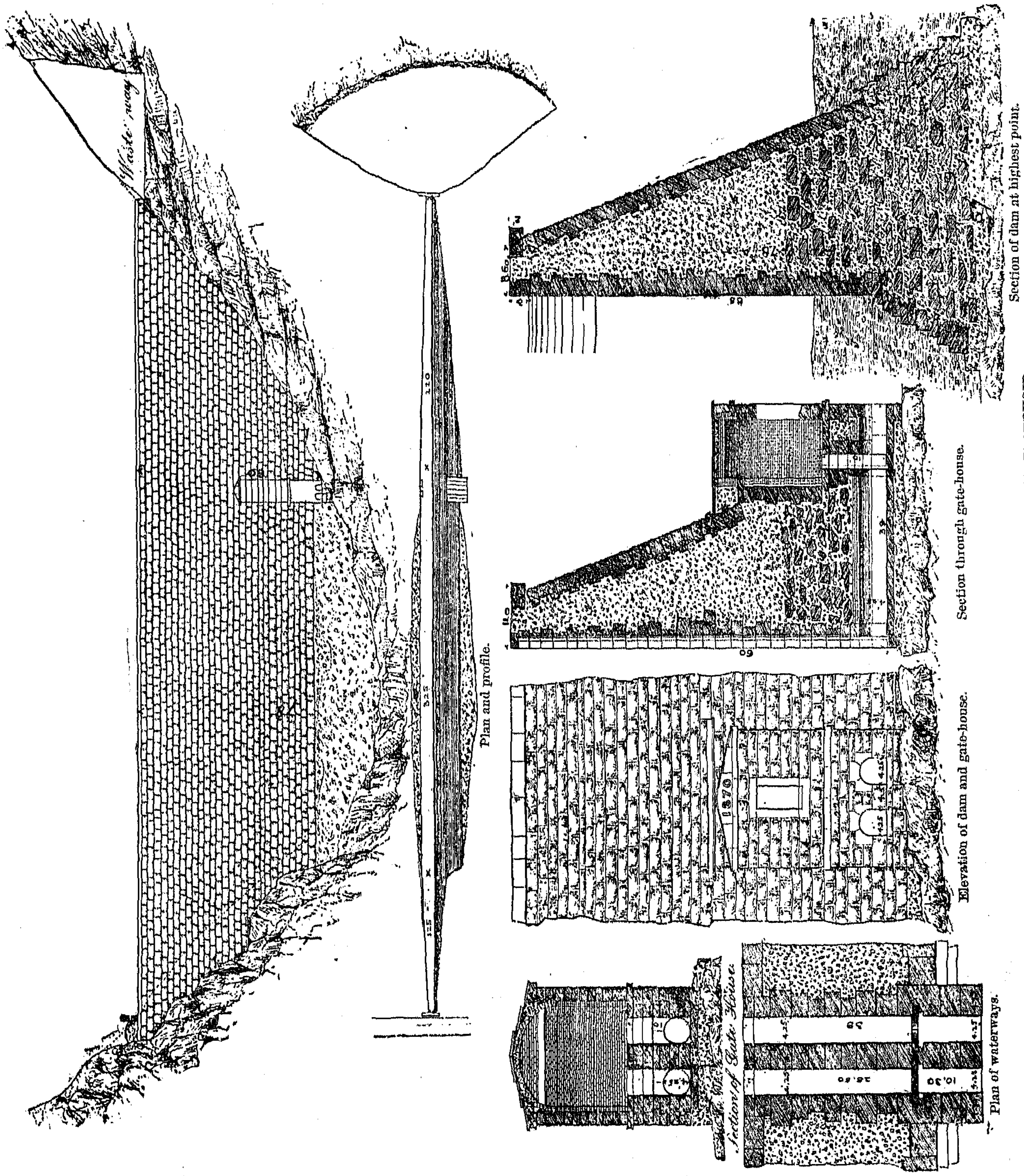
The cut (page 9) shows many details, which need, therefore, no description. Below the stream-level the foundation is of concrete, with large unhewn stones scattered through it, as shown. Above this level hewn blocks in courses face the concrete on the upper and lower sides. The large stones in the concrete center extend for 15 feet above the stream, and above this only gravel and small stones are used.

The lower line of the masonry is 325 feet from end to end, and at top it is 670 feet long. The upstream face is vertical, the other is inclined, with a batter of 1 to $2\frac{1}{2}$. Total height above rock bottom, 78 feet; width or thickness at base, 57 feet; at top, exclusive of coping, 8.6 feet. High-water surface, 3 feet below top of dam.

The gate-chamber, which is built on the lower side and near the left bank, is a plain arched chamber of brick-work, about 22 by 18 feet, and contains the gearing and appliances for operating the gates. There are two water-ways through the dam, a length of 39 feet, and each is 4.25 feet wide by 4.25 feet high, of brick in cement. The bottoms are 10 feet below the floor of the gate-house, and are 4 feet apart. Total depth of floor of water-ways below top of dam, 60 feet. A waste-weir is excavated in the rock around the left end of the dam, and the overfall at that end was arranged in three sections, the one at the extreme end cut in the rock, being 30 feet long at flow-line, the

a Published by the society in February, 1875.

second 9 inches higher over the masonry and 100 feet long, and the third 1½ foot above flow-line and 70 feet long. The rock at the base of the face-wall was cut in steps for 220 feet. Grooves for stop-plank were built in the upstream face of the dam over the water-ways.



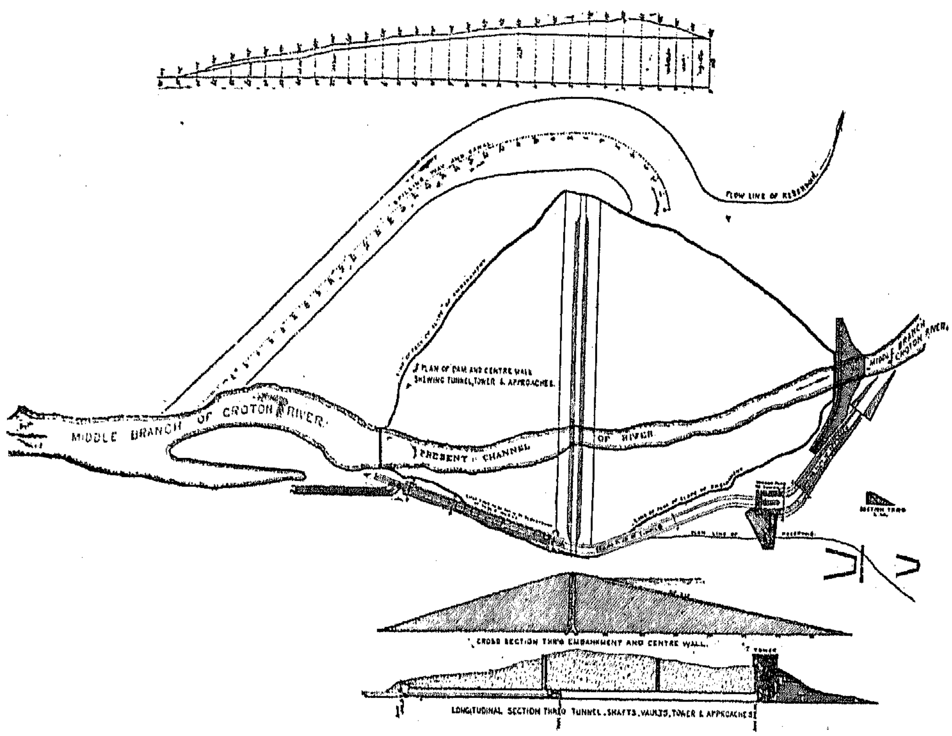
CROTON WATER WORKS.—MASONRY DAM FOR STORAGE RESERVOIR.

An earth embankment was built against both sides of the dam for 10 feet above stream-level. A change in the management of the Croton aqueduct department occurred in 1870, when the construction was nearly completed. The new officers altered the original plans and built an earth embankment against the upstream or vertical face of the dam, with a slope of 5 to 2, and 20 feet wide at top. At the toe of the slope, in front of the water-ways, a masonry tower was built above the water-surface. Grooves for stop-plank were built in it, and from its foot two 36-inch iron pipes were laid through the embankment and water-ways, and carried several hundred feet below the dam. The rock excavation at the end of the same, for the waste-weir, was increased to 100 feet in width.

The result of these changes was to change the dam from one amply strong for any water-pressure, to a retaining-wall for a saturated earth embankment, so near the limit of stability as to be almost if not quite unsafe, the earth being more or less pervious, and no puddling having been used.

The cost of the whole to the completion of the original design in 1870 was $370,000, and the total cost to the same date, including land, dam, roads, and engineering, was $590,000. Shortly after its construction the water led through the water-ways was converted into spray by a fountain-jet located a short distance below the dam, and constructed for the purpose of aerating the water.

The dam on the Middle branch of the Croton river was constructed in 1878 by E. H. Tracy, chief engineer of construction. It is an earth embankment, with a central priming-wall of rubble masonry extending from rock bottom to within a few feet of the top of the embankment.



PLAN OF DAM FOR STORAGE RESERVOIR ON MIDDLE BRANCH OF CROTON RIVER.

The waste-weir is a channel cut in the rock, and, as in the Boyd's Corner dam, the water is drawn off through a tunnel in the rock around one end of the dam.

The dam is 740 feet long at top, raising the water-surface to 370 feet above datum. It is 50 feet wide at top, and the thickest part of the bottom is 380 feet. Total height from bottom of foundation of wall, 91 feet. Depth at which water is drawn, 63 feet. Slope of water-face, 5 to 1; of downstream face, 3 to 1. The top is 10 feet above high-water surface. Thickness of central priming-wall, which rises to within 3 feet of the top of the dam, 8 feet. This wall is built of rubble in cement masonry, and is of the same thickness throughout most of its height, save at its base, where it is increased to 16 feet. The face of the dam is riprapped 3 feet deep with rubble in cement, laid upon the face of the earth bank. The capacity of the reservoir formed is 4,004,000,000 gallons, with a water-surface of 433 acres. The ground submerged was entirely meadow-land.

A waste-weir cut in the rock at the westerly end and around the dam is 100 feet in width, joining the river-bed about 320 feet below the foot. The water is drawn from this reservoir through a tunnel around one end, and started above the inner toe of the dam, as shown in the cut, 63 feet below high-water mark and 285 feet long, fitted with screens and gates. Immediately after passing the middle of the dam two 30-inch iron pipes, with 30-inch stop-gates, replace it and convey it to the toe of the lower slope, where four 20-inch mains discharge the water in the fountain for aeration into the bed of the river below the dam.

The Croton aqueduct begins at the gateway, 180 feet below the outlet to Croton lake, and at this point is an arched conduit of brick in cement. Details of the gateway are shown in the cut. At this gateway the water passes through an arch in the bulkhead, *a a*, the screens of brass netting, the guard-gates, and, lastly, through the regulating gates into the aqueduct. The aqueduct at the gateway is enlarged in width as shown, and is again diminished below the gates. The guard-gates are of cast iron in iron frames, and the regulating gates are of gun-metal. The following description is from the *Report of the Department of Public Works*, June 30, 1878:

The bottom is an inverted arch, the chord or span line is 6 feet 9 inches, and the versed sine 9 inches.

The masonry of the side walls rises 4 feet above the spring line of the inverted arch, with a bevel of 1 inch to a foot rise, or 4 inches on each side, which brings the width of the top of the side walls 7 feet and 5 inches, forming the abutments of the roofing-arch, which is a semi-circle, having a radius of 3 feet 8½ inches, or a chord line of 7 feet 5 inches. It will therefore be perceived the greatest interior width is 7 feet 5 inches, and the greatest height 8 feet 5½ inches. The area of the interior is 53.34 square feet. In rock tunnels the roofing-arch is generally dispensed with, but the bottom and sides are formed with masonry similar to the above described.

There is an exception to this form in the first 4.949 miles of the upper end of the aqueduct, where the side walls have an extra height *on account of the bottom being depressed to draw the water at a lower level from the Croton reservoir. The plan, dimensions, and* character of masonry are as follows: In excavation a bed of concrete masonry is laid down as a foundation. It is laid level across the bottom 3 inches thick at the center of the inverted arch, and covered on its upper surface to form a bed for the arch, which brings it 12 inches thick at the spring line, and is carried 3 inches thick under the side walls or abutments. The abutments are 2 feet 8 inches thick at the spring line of the inverted arch, and 2 feet at the top or spring line of the roofing-arch. The inverted arch is of brick, 4 inches thick. The roofing-arch is also of brick, 8 inches thick. The abutments or side walls are of rubble-stone with a brick facing 4 inches thick. Spandrels of stone are caried up solid from the exterior angle of side wall, on a line that is tangent to the arch. Where the bed of concrete is formed for the inverted arch a heavy course of plastering is laid over it, on which the arch is laid. When the stone wall of the side walls was up, the face that received the brick lining had its irregularities filled with successive courses of plastering, and finally a uniform course of one-fourth of an inch in thickness over the whole, in front of which the brick facing was laid up. A course of plastering was also put over the roofing-arch.

DAM, Bulkhead and Gateway

Fig. 1.

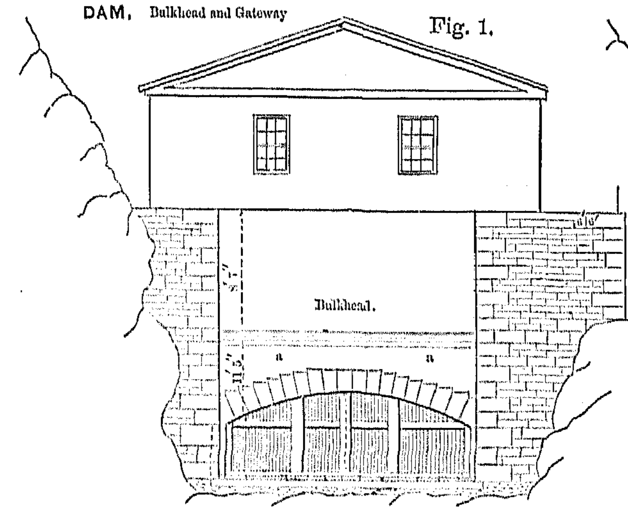


Fig. 2.

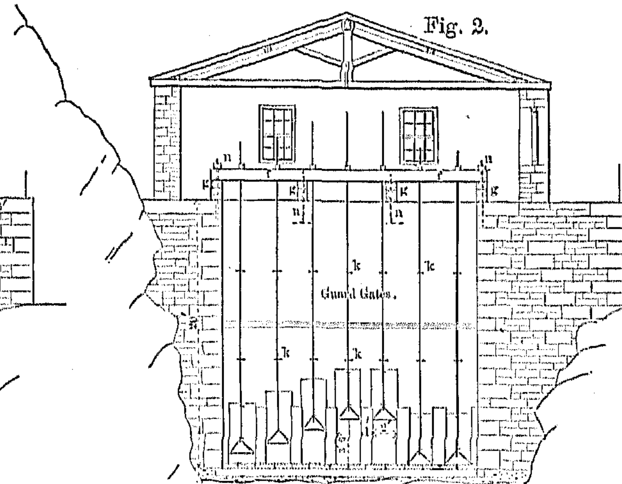
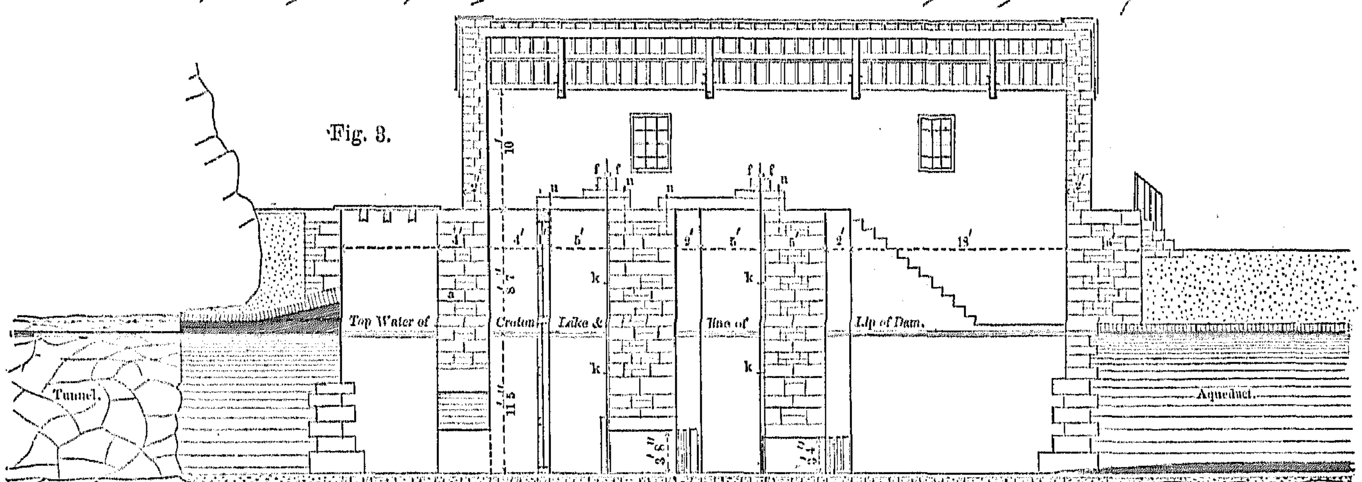
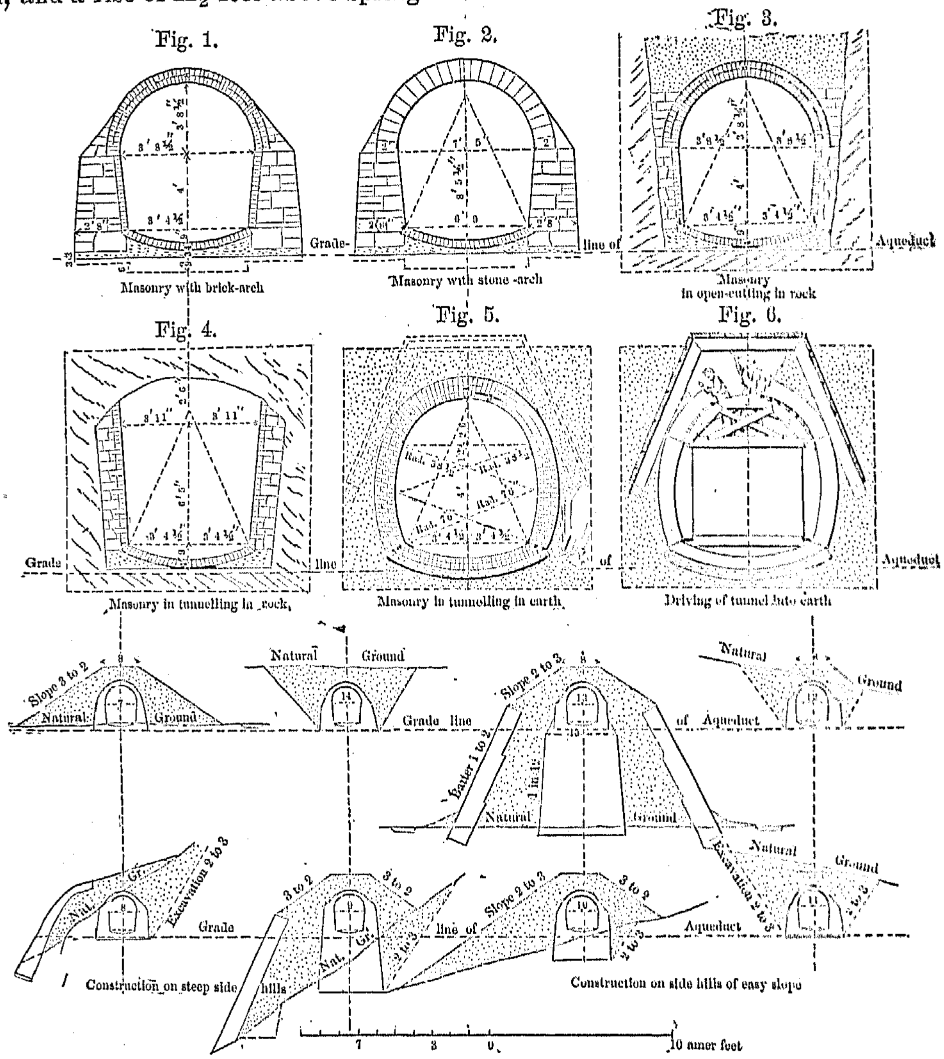


Fig. 3.

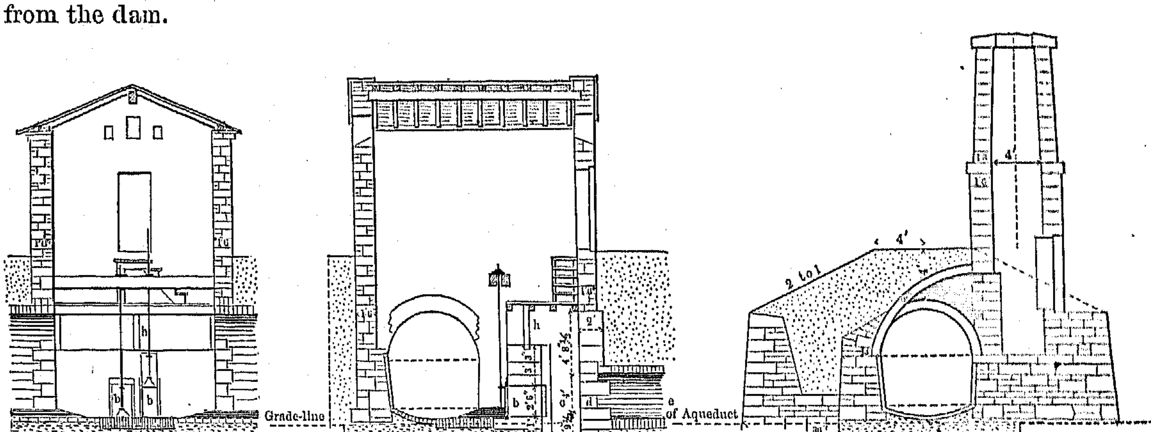


Below this point the aqueduct extends 1 mile along the river-bank to Lounsberry's brook, which it crosses with a culvert 66 feet long and 6 feet wide, and 44 feet above stream-level. After extending 5 miles farther it crosses India creek, also on a culvert 142 feet long, 8 feet wide, and 58 feet high. Near this it is tunneled through two hills; one of these tunnels is 740 feet in length, and the second 116 feet long. Half a mile farther, Hoag's Hill tunnel, 276 feet long, is encountered. From here it extends to Sing Sing tunnel, crosses a street in Sing Sing and Kill river *on an aqueduct bridge, the large or river span of which is* 88 feet span by 33 feet rise, the crown of the arch being 62 feet above ordinary river-level. The arch is of stone, about 3 feet thick at the summit. From here it passes through the Prison Farm tunnel, about a mile below, an earth and rock cut 416 feet long, and, a short distance beyond, through another of 375 feet length. Still farther, at a distance of 9½ miles from the dam, it passes Hale's Brook tunnel, 260 feet long, and then crosses the brook on a culvert viaduct, the culvert being 6 feet wide, 131 feet long, and 49 feet below the top of the back-filling. A mile below this point Rider's brook is crossed by a culvert 100 feet long, 6 feet wide, and 34 feet high. Near by it crosses a highway by a bridge similar to that over Kill river, and at 11½ miles from the dam passes through Austin Farm tunnel, 186 feet long. It crosses Mill river 13 miles from the dam, on an aqueduct bridge 25 feet wide and 172 feet long. In the next 2 miles are 5 culverts, and a tunnel 246 feet long through rock, known as the White Plains tunnel. Another, at Dobbs Ferry, is 262 feet long, driven through earth. The cut on page 12 shows the various forms at different places. From this point to below Yonkers there are a number of culverts, and at the latter place is a tunnel known as the Saw-Mill River tunnel, through earth, and 684 feet long. Beyond this is the Saw-Mill River bridge, a stone structure in 2 arches, each 25 feet span, and a rise of 12½ feet above spring line.



Tibbits Brook tunnel, 26 miles from the dam, is in solid rock, 810 feet in length, and is succeeded by a culvert over the brook. The last 2 miles are in favorable ground. Waste-weirs and ventilators, as shown in the cut, are built at various points on the aqueduct.

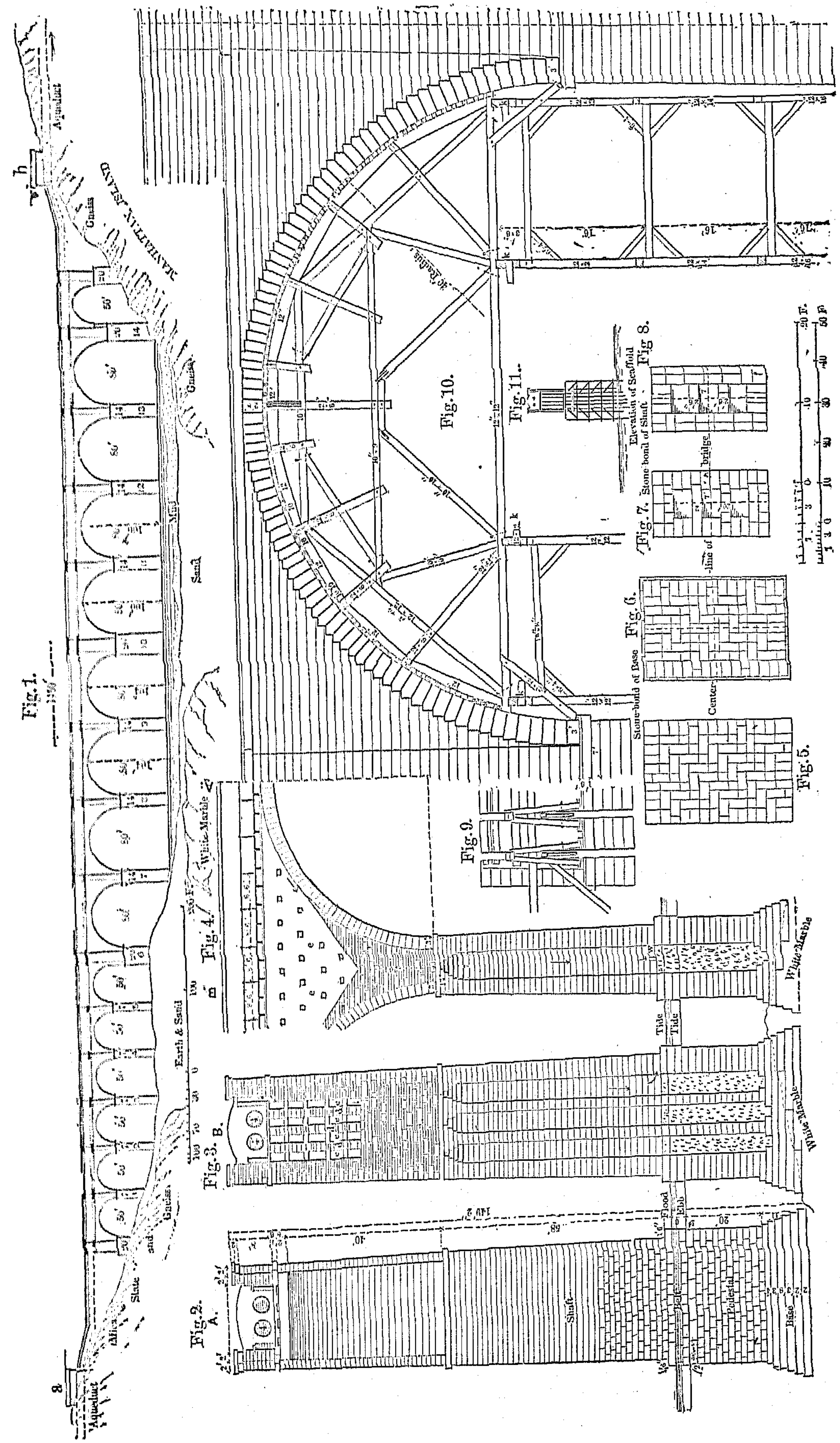
The next structure of importance is the great aqueduct bridge over the Harlem river, known as High bridge, 33 miles from the dam.



It was originally intended that the Harlem river should be crossed by an inverted siphon under the bed of the river, and this could have been built at a fraction of the cost.

The mainland bank here has a slope of 20°, and the island bank has a slope of 35°. The country rock is here gneiss, extending beneath the river at a sharp declivity, and the central depression between banks contains a deposit of white marble.

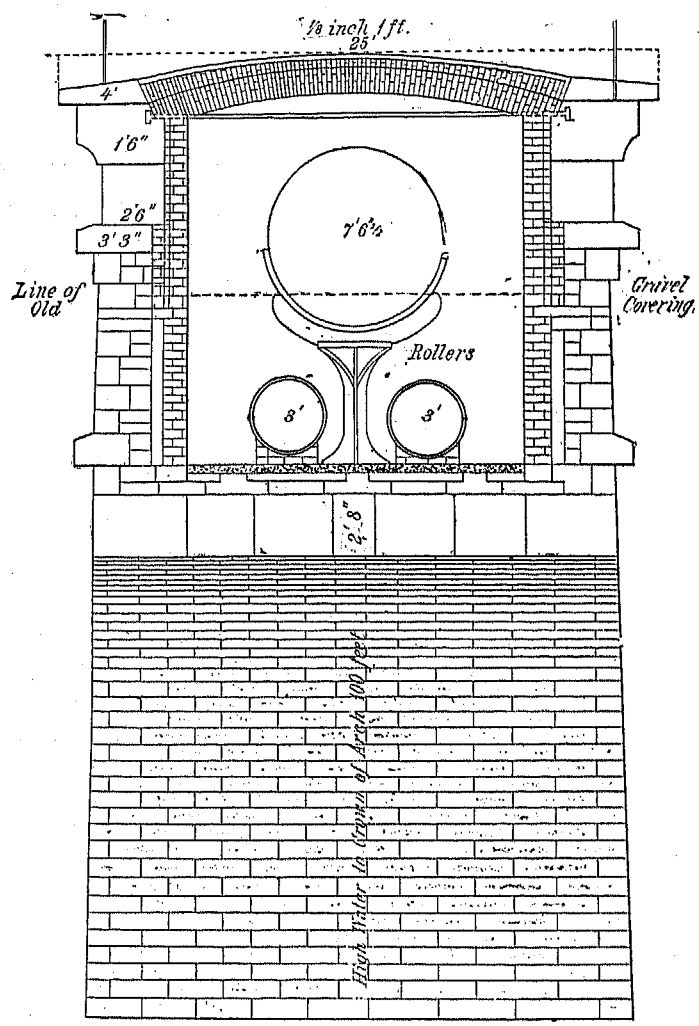
The bridge has fifteen arches—eight of 80 feet width by 100 feet height above flood-tide, over the water, while seven of them are upon the shores.



ELEVATION AND SECTION OF HIGH BRIDGE.

The two abutments and piers Nos. 1, 2, 13, and 14 are founded on gneiss, and 7, 8, and 9 upon marble, the remainder being upon piles. In this way the inverted-pipe siphon is depressed only 12 feet in crossing the bridge. To construct the water-piers, coffer-dams were built.

The piles, driven to refusal, were 11 inches in diameter, 2½ feet apart, of oak, capped with 6-inch planking, and cross-capped on this with 6 inches more of the same material. Upon this the masonry was built of gneiss rock, dressed and laid in concrete at bottom and cement above the few lowest courses. The centering and scaffolding are shown on page 13.



TRANSVERSE SECTION OF HIGH BRIDGE AS ALTERED.

The two original pipes were arranged as shown in the cut, and were 3 feet in diameter. Later a third pipe, 7 feet 6½ inches in diameter, was added and the coping raised as shown. The small pipes were originally laid upon small wooden sills 6 inches wide by 9 inches; these sills were finally replaced by saddles of concrete. At each end of the bridge is a gate-house, the interior of which is arranged in one chamber containing four gates, closing the mouths of the pipes, and the latter are somewhat bell-mouthed, to assist the flow into them. The conduit ends on a level in one end of the chamber, and the pipes descend 12 feet to the level of the top of their resting-places on the bridge. The efflux-chamber is 2 feet lower than the influx-chamber. A waste-weir is built in the influent gate-house, discharging at right angles to the line of pipe, by which the conduit may be emptied. It is controlled by iron gates.

At the southern or effluent end of this aqueduct bridge a pumping-station has been erected, with a small distributing reservoir on an eminence near by, and an elevated tank in close proximity to the pumps. These will be described later. They are for the supply of the high lands of Washington Heights and Fort Washington. A short distance beyond them the aqueduct passes a ravine 30 feet deep, and then a tunnel 234 feet long, in rock, and known as the Jumel tunnel, 33½ miles from the dam at Croton lake. After crossing two ravines, one 38 and one 43 feet deep, the conduit extends along Tenth avenue to the great depression at Manhattan street, just before reaching which it passes its longest tunnel, known as Manhattan tunnel, 1,215 feet, in rock. The aqueduct then crosses Manhattan valley through four 36-inch iron pipes, starting from the end of the tunnel in an influent gate-chamber similar to that at High bridge. The pipes are laid as inverted siphons, side by side, the maximum depression being 105 feet below the grade-line of the aqueduct. The total length is 4,180 feet to the effluent gate-house on Asylum hill, opposite, and similar to that last mentioned. At the latter point the water enters again the continuation of the conduit, which passes through a tunnel under Asylum hill, 640 feet, in rock, to Glendenning valley. The aforementioned siphon-pipes in Manhattan valley have discharge- or waste-pipes at their lowest point in the valley, which discharge into the sewers over a waste-weir, the object being to empty the siphons if necessary. In 1854 an additional pipe, 48 inches in diameter, and in 1861 another, 60 inches in diameter, were laid across this valley.

Glendenning valley is a depression 2,000 feet long and 50 feet below conduit-level, extending from Ninety-sixth street to One hundred and fourth street. It was crossed on a viaduct, arches of masonry 30 feet wide being built over most of the streets, and two smaller ones of 9 or 10 feet each over the sidewalks. In 1875 this viaduct, and the portion of the aqueduct included with it between Ninety-second and One hundred and thirteenth streets, were replaced by four lines of 48-inch pipes laid under Tenth avenue. The whole line of the conduit where elevated above the level of the country is protected by a turfed covering of 4 or 5 feet of earth. Within the last few years most of the aqueduct below One hundred and thirteenth street has been removed or disused, and two iron mains, 6 feet in diameter, have been laid from Ninety-second street and Ninth avenue to Eighty-fifth street and Eighth avenue, and connect with the aqueduct reservoir in Central park, known as the Old Basin. In all there are 33 ventilating openings in the length of the aqueduct. At Ninety-second street and Ninth avenue two stone gate-houses have been erected over the conduit, at which the mains connecting with the new reservoir are joined. There are two sets of gates, by means of which the water may be sent either into the new reservoir through the conduit, or continued to the old receiving reservoir. The whole contents may therefore be sent to one or the other of the reservoirs, or may be divided between them.

At Ninety-seventh street and Ninth avenue a high-service pumping-works has been erected on the line of the conduit, for the purpose of supplying the higher portions of the city below One hundred and thirtieth street. This will be hereafter described. The aqueduct has been a constant source of trouble, owing to breakages and leaks caused by unequal settling of the ground through which it passes, and its capacity is overtaxed.

The old receiving reservoir is located in Central park, on the lines of Sixth and Seventh avenues and Seventy-ninth to Eighty-sixth street. It is rectangular in plan, in two divisions, separated by an embankment. The northern division is 24 feet and the southern 29 feet deep, and both are filled to within 4 feet of the top. Its capacity is 150,000,000 gallons. The banks are of earth with puddle interior, the sides bordering upon the lines of the streets and avenues being walled with masonry, and the inner faces riprapped with dry stone 15 inches thick. The bottom is of natural rock or earth. The north basin, and the larger of the two, is about 930 by 645 feet, and the south basin 645 feet square on the bottom. The division bank is also faced with dry riprap, and all of the faces slope $1\frac{1}{2}$ to 1 on the inside. A $2\frac{1}{2}$-foot pipe, with stop-gate, with its bottom 15 feet below high-water surface, passes through the division embankment and keeps the water-level the same in both compartments. A waste-weir in one end of the division bank allows excess of water to flow over its top into the bottom of a well, and thence into the sewer. There is one influent gate-chamber in the northern basin connected by a sluice channel with the other, and four effluent chambers, one on the east and one on the west of each basin. From this reservoir, which was built in 1840, and which is 6 miles from the end of the city, the mains formerly extended to a distributing reservoir at Fortieth street and Fifth avenue. This latter is a heavy cut-masonry basin, square in plan, and 400 feet long at the water-line. The walls are double, and are connected by arches, leaving a long series of chambers through the heart of the work. An earth filling supports the water-face or riprap wall. Capacity 24,000,000 gallons. It is probably soon to be removed.

The new reservoir in Central park is irregular in outline, with a capacity of 1,200,000,000 gallons. It is in embankment chiefly, with a puddle-wall through the center and a division-wall separating it into two basins. Area of water-surface 96 acres, depth 36 feet. The banks are 18 feet wide at top, slope $1\frac{1}{2}$ to 1 inside. The puddle-wall rises to 2 feet above high-water mark. Division embankment $12\frac{1}{2}$ feet wide at top, with both slopes, as well as those of the banks of the reservoir, faced with riprap of rubble in cement, 18 inches thick, on a foundation of 8 inches of concrete. The influent and effluent gate-houses of masonry are located at opposite ends of the division-wall. The aqueduct enters the former at the northerly end of the division-wall, and the water can be sent into either division. Effluent pipes, four in number, leave the northern gate-house, and are 36 inches in diameter. Another effluent gate-house at the southern end of the reservoir has six 48-inch supply-pipes leading from it.

The total revenue derived from "Croton water", from its introduction into the city in 1842 to September 18, 1880, amounts to $36,363,953.

The following statement shows the total amount expended for works, structures, aqueducts, pipes, etc., connected with the water-supply of the city of New York, including maintenance and repairs, from the period of its inception to January 1, 1880:

To January 1, 1865	$20,030,221 93
During the year 1865	224,337 27
1866	442,628 05
1867	581,794 80
1868	726,437 40

During the year	1869	$894,628 19
	1870	1,172,078 48
	1871	2,784,440 72
	1872	1,836,847 68
	1873	2,049,850 51
	1874	1,465,708 03
	1875	882,777 64
	1876	1,066,645 50
	1877	859,670 68
	1878	802,014 58
	1879	619,221 00

Total to September, 1880, $37,212,995.

The supply from Croton river, which was analyzed by Prof. C. F. Chandler, and the water of the Housatonic river, one of the proposed sources for increased supply, show the following indications of purity:

		Housatonic.	Croton.
Chloride of sodium	grains.	0.2019	0.284
Sulphate of potash	do...	0.1300	0.205
Sulphate of soda	do...	0.1842	0.024
Sulphate of lime	do...	0.0489	0.024
Carbonate of lime	do...	3.0362	1.698
Carbonate of magnesia	do...	1.5430	0.935
Alumina and oxide of iron	do...	0.0816	0.058
Silica	do...	0.5540	0.222
Organic and volatile matter	do...	0.5832	0.874
Total solids	do...	6.3630	4.324
Hardness	degrees.	3.6	2.5
Free ammonia	parts in 1,000,000.	0.0210	0.0700
"Albuminoid ammonia"		0.0674	0.2450

The works at High bridge for the high service of Washington Heights, etc., consist of an engine-house, boiler-house, and coal-shed, force-main to reservoir, small reservoir, and an auxiliary pump supplying a tank on the top of a tower. The engine-house, of brick and stone, is 40 by 25 feet, and arranged for two engines. The water is drawn through two 30-inch iron pipes 115 feet long, from a chamber about 4 feet wide connected with the aqueduct a short distance after its exit from the effluent chamber on the bridge. There are two pumping-engines, designed by William E. Worthen, of New York, one built in 1870, by the Hartford Foundery and Machine Company, and the other in 1876, by the Delamater Iron Works of New York. The former cost, in the prosperous times of 1870, about $40,000, and the latter only $29,000. Their capacity is about 5,000,000 gallons per day, and they are run alternately during the whole day. They are condensing-engines with a duty of from 25,000,000 to 35,000,000 foot-pounds, with single-acting pumps, plunger displacement. When the present improvements are completed there will be two multitubular boilers for these engines. Each is 17 feet long by 7 feet diameter of shell, with ninety-six 4-inch tubes in each, and operated at 45 pounds pressure. From the pumping-station two 20-inch force mains extend to the reservoir, 900 feet distant. The latter, of 10,000,000 gallons capacity and situated 216 feet above datum, is in embankment with a central puddle-wall 16 feet high, 4 feet thick at top and 10 feet at bottom. It is square in plan, measuring 322 feet at the high-water line. Inner slope $1\frac{1}{2}$ to 1, outer $2\frac{1}{4}$ to 1; width of banks 12 feet on top. The inner face is riprapped 18 inches thick with rubble in cement laid upon the earth banks direct. The water-line is 2 feet below the tops of the banks, and the high-water depth is 16 feet. A small Worthington pump located near the reservoir takes water from the conduit or aqueduct and forces it into a tank of 44,000 gallons capacity at the top of a brick and stone tower, 335 feet above datum, and 160 feet high to water-line. The tank is of wrought iron, and is intended to supply a few very elevated points in the vicinity. The total cost of this double high service at the High bridge, including reservoir, tank, engines, tower, etc., amounted to $610,000.

The high-service works at Ninety-seventh street and Ninth avenue, on the line of the former Glendenning bridge, consist of a brick building 50 by 200 feet, extending from Ninety-seventh to Ninety-eighth street; at one corner, on Ninety-eighth street, a stand-pipe, inclosed in an ornamental square brick tower, rises 170 feet. Here are two Worthington engines drawing their supply from a 48-inch main from the new receiving reservoir through Ninety-eighth street. They are of large capacity, capable of pumping, according to records of the engineer, over 8,250,000 gallons per day. Only one is run at a time during 24 hours per day. Space is left in the engine-house for another. The dimensions are as follows: Steam-cylinder, low-pressure, 36 inches diameter; steam-cylinder, high-pressure, 21 inches diameter; water-pistons, 28 inches diameter; stroke, 48 inches; back pressure from reservoir, 7 feet; pressure on pumps averages 37 pounds; air-pumps, 16 inches diameter by 16 inches stroke; condenser, 28 inches diameter by 48 inches high; 4 boilers, 6 feet diameter by 15 feet long, containing seventy-five 3-inch tubes in each; average steam-pressure, 45 pounds. The stand-pipe, of wrought iron, is 170 feet high by 6 feet diameter, with a spiral staircase around it inside of the brick casing. Water is forced into it at present to the height of only 120 feet. It has one 36-inch inlet and one 36-inch outlet. The distribution, which amounts to

506 miles, is carried out through iron pipes, most of which, from 1858 to 1870, have been coated inside and out before laying, save a few laid in 1870 to 1874, which were not thus coated. They are of 4 inches to 48 inches diameter, and are tapped up to 20 inches only. The consumption approximates 95,000,000 gallons per day.

There are in all 6,210 fire-plugs in the city, mostly of the Ayres pattern, patent hydrants being forbidden by law.

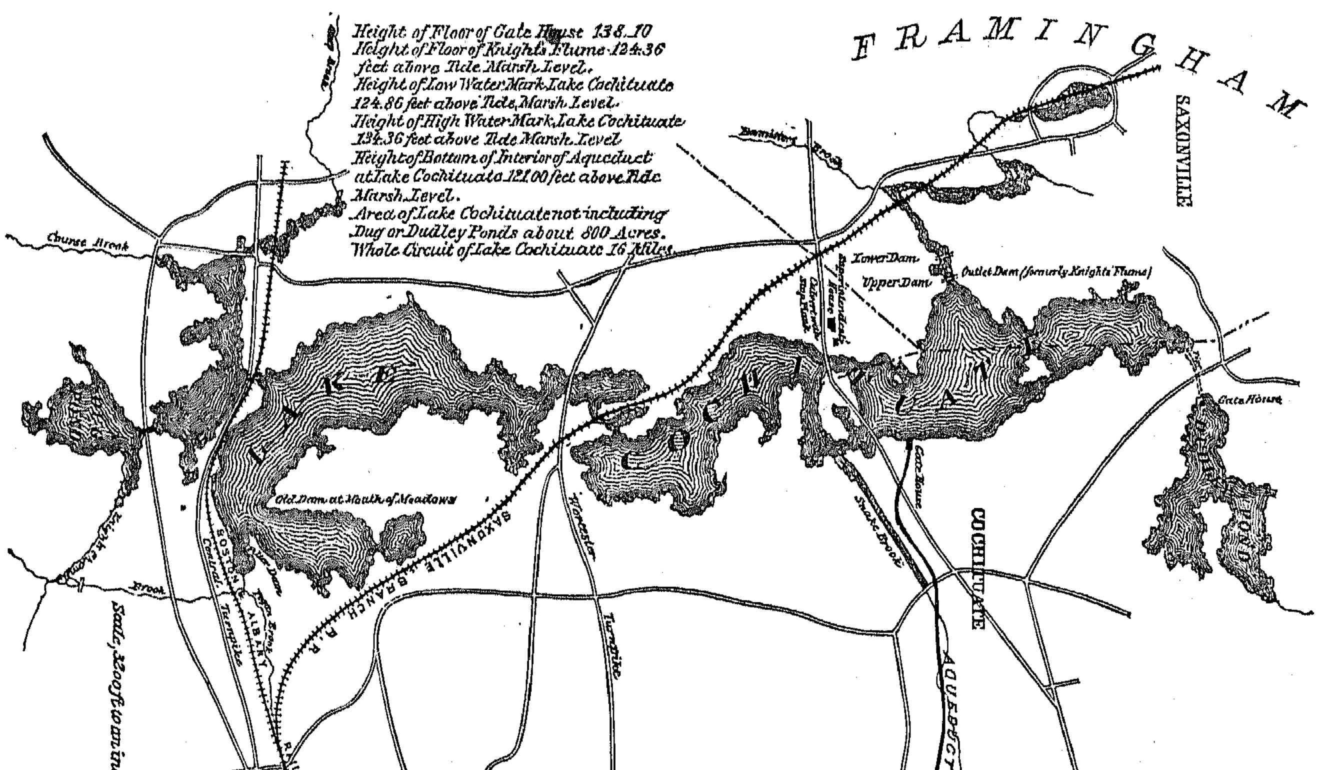
The annual cost of maintenance and repairs amounts to about $200,000, and the city pays nothing for water consumed in the public buildings and places.

Rates are assessed upon the frontage of lots, with special rates for various industries and establishments. By meters, of which there are 3,313, the rate is 7½ cents per 100 cubic feet.

The works are under the charge of Isaac Newton, C. E., as chief engineer, with G. W. Birdsall as first assistant engineer.

BOSTON, MASSACHUSETTS.

Boston contains 362,839 inhabitants. In addition to the ancient "Tremont", or Boston proper, the present city limits embrace several formerly independent towns and cities, notably Roxbury, Charlestown, and Dorchester. In the older portions the streets are proverbially irregular, while the topography is uneven. Water was introduced into the city in 1848. The system as at present existing is a gravity supply. Lake Cochituate, the main source of supply, is a chain of natural subsiding reservoirs of water, three in number, having a general direction nearly north and south (see map), its extreme length in a direct line being about 3½ miles, and its greatest breadth about 1,800 feet. Two county roads crossing it divide it into three nearly equal parts, designated as the northern,



MAP OF LAKE COCHITUATE.

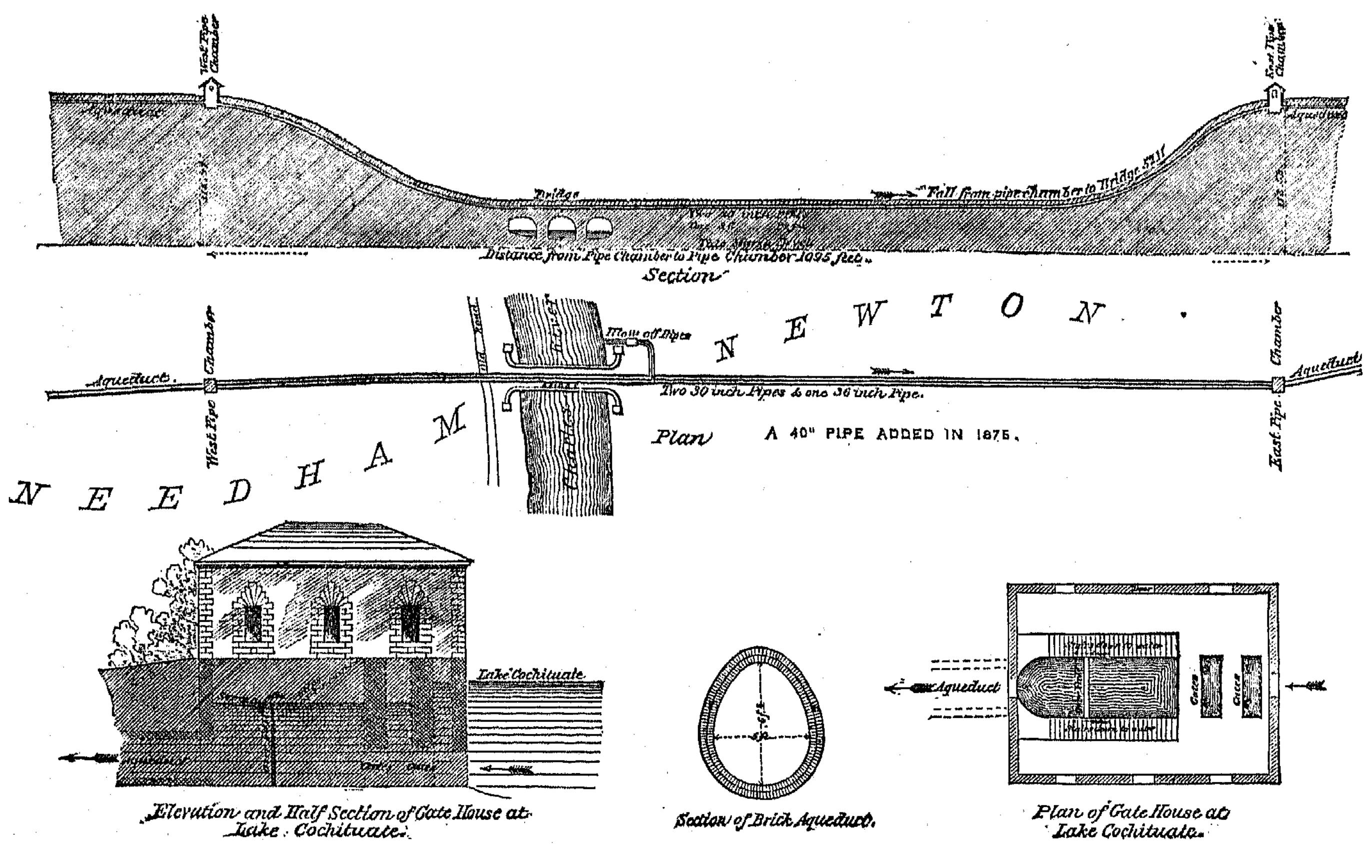
central, and southern divisions. The water gradually increases in depth from the shore in each division; at high water, or when raised 10 feet above the flume, or 13.36 feet above the bottom of the conduit, its greatest depth is about 72 feet in the southern, 50 in the center, and 64 feet in the northern division. When the water is at this elevation, the superficial area of the lake is estimated to be 800 acres. At 3 feet 5 inches above the bottom of the conduit the area of the lake is 490 acres, and its capacity is 13,313,000 wine gallons; for every inch added to the above height up to 5 feet there is an increase of 1 acre in area, and the total capacity is increased to 270,834,000 wine gallons. At 13.36, or high-water mark, the total capacity of the lake is 2,011,165,000 wine gallons, and the area 801 acres. The shore of the lake is generally a bold sand and gravel bank, and the increase of surface which is produced by raising the water takes place mostly in a great meadow in the southern division. The whole circuit of the lake, including the meadows, is about 16 miles, and, excluding those, about 12 miles, measured at the verge of the lake, when the water is 8 feet above the flume.

The tract of country which drains into the lake is bounded by the ranges of hills which divide the streams running into the Merrimack from those which run into the Charles river, and, as surveyed, covers an area of 11,400 acres, or 496,584,000 square feet, as the water-shed from which the lake derives its supply.

The flume referred to above was known as "Knight's flume", and was used for manufacturing purposes. The floor of this flume was 3.36 feet above the bottom of the conduit; the waters of the lake were at first raised to 8 feet above the floor of the flume, but afterward to 10 feet, the cost of the last 2 feet being $27,130, which included the damages paid for submerged lands.

There are two dams at the outlet, which is on the west side of the northern division. The first is of solid masonry or granite, and raised to a height sufficient to retain the water to a point 10 feet above the floor of the flume. This corresponds with an elevation of 134.36 feet above tide-marsh level, the floor of the flume being 124.36 feet above the same level. The second dam is at a distance of about 500 feet below the first, and is for the purpose of lessening the pressure upon the upper dam; it also is of solid masonry, with an overflow of 23 feet in width.

The gate-house at the lake is situated on the eastern side of the northern division opposite to the dam, and is built a sufficient distance into the lake to admit the water from the necessary depth. The bottom of the aqueduct, which here begins, is placed at an elevation of 3.36 feet below the floor of the flume. When the lake is raised to the high-water mark it will stand 13.36 feet above the bottom of the conduit. In the house there are four gates for regulating the admission of water into the aqueduct. They are of cast iron, with composition or gun-metal facings, and a frame of the same materials, set in hammered stone. This building is 29 feet 6 inches by 39 feet 6 inches, of hammered granite, with a metal roof. The floor is of granite, and there are two flights of granite steps from the floor down to the conduit. A stone culvert is also constructed beneath the road, which divides the northern from the central division, in which provision has been made for placing stop-planks so that the water can be shut off from the northern division, and thereby about two-thirds of the water in the lake can be retained in case it should be necessary to repair the gate-house or dams.



PLAN AND SECTION SHOWING METHOD OF CONVEYING WATER ACROSS CHARLES RIVER.

Dug pond is south about 113 feet from the southern shore of the lake, and is separated from the peat meadow, on the southern division, by the county road; a culvert, 2 feet in diameter, is laid beneath the road, by which the waters are discharged into the meadow and thence pass into the lake; the pond contains about 44½ acres. The shore all around is a steep gravelly bank, 8 or 10 feet high, and the pond naturally derives its waters wholly from springs. The water is quite deep and remarkably pure and soft, and forms a highly important tributary to the lake. High-water mark in this pond is 17 feet above Knight's flume. The town of Natick now obtains a supply from this pond, so that its value to the city has been somewhat diminished.

Dudley pond lies in a northeastern direction from the northern division of the lake, and contains 81 acres, at an elevation of about 12 feet above the lake. There is no other outlet than that through which it flows into Sudbury river. This pond was connected with the lake in the year 1861, by means of iron pipes 18 inches in diameter and about 800 feet long, which pass under the road. High-water mark in this pond is 22.1 feet above Knight's flume, and 146.46 feet above tide-marsh level.

The aqueduct, for convenience in its management, is divided into two divisions, the western and the eastern. The western extends from the lake to and including the receiving reservoir in Brookline. The eastern begins at the Brookline reservoir, and comprises all the iron mains from Brookline to the city and the distribution in the city.

The conduit, from the lake to the left bank of Charles river, and from the right bank of the same to Brookline reservoir, is built of brick masonry 8 inches thick, laid in hydraulic cement. It is in section an egg-shaped oval, the larger end down; the greatest width is 5 feet, and the extreme height 6 feet 4 inches in the interior. It is covered with a plastering of hydraulic cement on the outside, from the top down to the chord-line of the lower or inverted arch. It is supported on a puddled embankment, built up above the chord-line of the inverted arch in all cases where the aqueduct passes over ground the level of which falls below the grade-line, and also where the ground was found to be marshy, or from any cause not sufficiently solid to support the superstructure. The whole is covered with an embankment 8 feet wide on the top, with side slopes of 2 feet horizontal to 1 foot vertical, and raised 4 feet above the top of the aqueduct. The aqueduct through the whole distance thus rests upon and is covered with earth to a depth of at least 4 feet, and is nowhere raised so as to admit a passage beneath it excepting at the culverts—at the crossing of Charles river, which it passes by four iron pipes, two of 30, one of 36, and one of 40 inches diameter—and where it crosses the valley in Needham near the west bank of the river. In the latter place it is carried over the roadway by a granite bridge of one arch of 20 feet span and 14 feet high, and from there to the west pipe-chamber on a puddled embankment, in some places 40 feet high. (For further details see the *History of the Boston Water Works*, published by the department in 1874.)

The remainder of this part of the aqueduct comprises the mains over the valley of the Charles river and the tunnels in Brookline and Newton. The former consist of four iron pipes, two of 30 inches, one of 36 inches, and one of 45 inches in diameter, which descend 52.11 feet below the level of the aqueduct on the west bank of the river, crossing on a stone bridge built over the river, and thence are continued over the intervale at a rather low level, and then rise to the aqueduct on the eastern side.

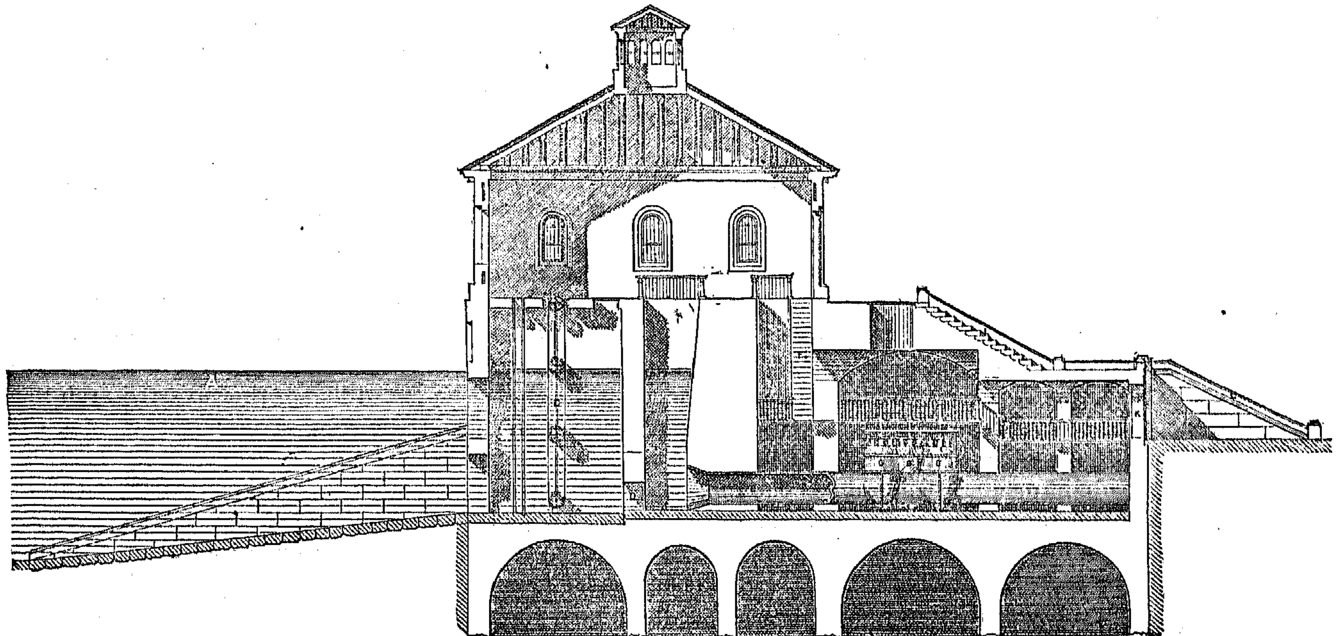
The Charles River bridge is constructed of hammered granite, of three elliptical arches, of 30 feet span and 7½ feet rise, and 21 feet wide.

The pipe-chambers, constructed at each end of the mains, are of granite; the horizontal distance between them is 1,095 feet. The admission of water is regulated by stop-planks. The bottom of the west pipe-chamber is 119.04 and that of the east pipe-chamber 118.58 feet above tide-level. The water in the river at its lowest state is 71 feet below the bottom of the brick conduit.

Chestnut Hill reservoir is a natural basin at a distance of about 5½ miles from the center of the city, and within the present municipal limits. An artificial bank was required only on the lower side of the valley. The reservoir is built in two parts, separated by a water-tight dam. A gate-house in the center allows of communication between the two basins. Both parts are of somewhat irregular form. Together they are 2½ miles in circumference. The land bought by the city for this reservoir amounted to 212½ acres. The combined capacity of both basins is 731,472,429 gallons. The easterly and the larger of the two basins is called the Bradlee basin, and has when full a water area of 87½ acres. Average depth of water, 20 feet. Its capacity is 550,583,485 gallons. On the easterly side of the reservoir and on the highest part of the embankment is the principal or effluent gate-house. It fronts on Beacon street.

The Lawrence basin has a water area of 37½ acres, and a capacity of 180,888,944 gallons. The distance around the center of the path which surrounds the Lawrence basin is 6,183 feet, or 1.17 mile. The effluent gate-house is the most important structure on the reservoir grounds. A bed of quicksand, 28 feet in depth, rendered the laying of the foundations a difficult task. Rubble piers with brick arches rest on the bed-rock and support the structure. These were leveled off on top with a layer of concrete; and a heavy bulkhead, side-walls, brick piers, and groined arches complete the remainder of the substructure. On the water side of the bulkhead are four separate compartments for four lines of 48-inch pipes. Each compartment has places for a double set of stop-planks, a revolving screen, sluice-gates, and an open well in front of the pipe. The superstructure is built of hammered granite. Outside of the bulkhead are gates placed in the pipes. Branch walls are built into the bank 80 feet long on one side, 25 feet on the other. Their section consists of 4 feet of rubble-wall laid in cement, and 2 feet of brick-work. Outside of this gate-house is a brick chamber under ground, which contains two gates. These control two lines of drain-pipes, which run through the embankment on arches. They connect with each basin, so that either can be drawn to its lowest level for cleaning or repairs.

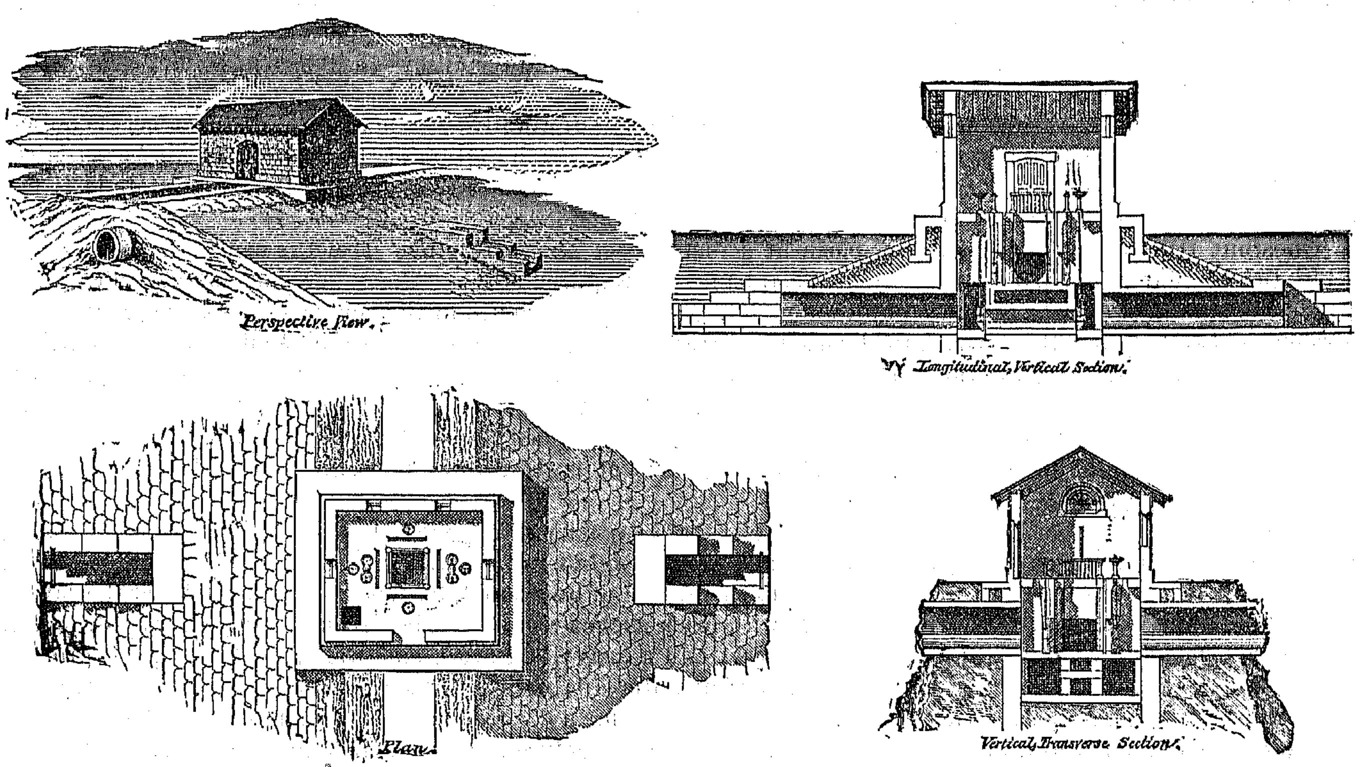
Two hydraulic sluice-gates worked by a hydrostatic press were placed in position during the winter of 1873–'74 in this gate-house. They are to shut off or let on the water to the 48-inch main. The need of gates at this point which can be quickly operated, has been felt ever since the reservoir was first used, and provision was made for



A, Reservoir; B, Stop plank; C, Rolling screen; D, Gates; E, 48-inch pipes; F, Stairs down from upper floor; G, Stop-cocks; H, Light pipe to chamber; K, Door under embankment; L, Steps up to gate-house.

LONGITUDINAL VERTICAL SECTION OF LOWER GATE-HOUSE AT CHESTNUT HILL RESERVOIR.

them when the gate-house was constructed. They have been designed with special reference to easy and rapid movement. One man can fully open either of them in less than 4 minutes, and they close by their own weight in less than 20 seconds, settling to their seats quietly. The openings are 48 inches square. The movement is vertical.



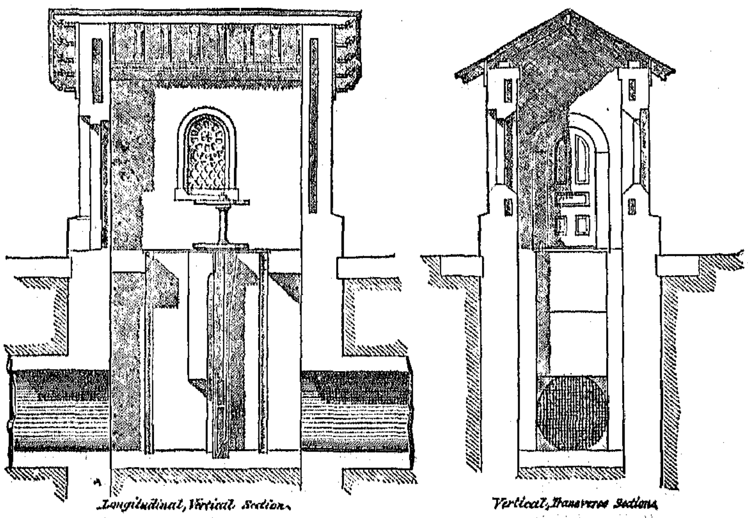
INTERMEDIATE GATE-HOUSE AT CHESTNUT HILL RESERVOIR.

When in motion the gates are carried on three pairs of wheels 12 inches in diameter. The seats are not exactly parallel to the gate-frame, being inclined slightly from the vertical, so that when the gate is closed the gate-face and seat are in contact, and the wheels are lifted a fraction of an inch from their tracks. Vertically over each gate is a cylinder fitted with a piston, 8 inches in diameter and of 4-feet stroke.

The intermediate gate-house, built in the center of the dam separating the two basins, is also located directly over the aqueduct, which runs lengthwise through the dam and continues to the Brookline reservoir. Four gates, one toward each basin and one on each end of the aqueduct, allow of turning the water any way. Beside these there are two lower-level gates connecting the two basins. There is also in one corner of this gate-house a gate communicating with a line of drain-pipe laid through the Bradlee basin.

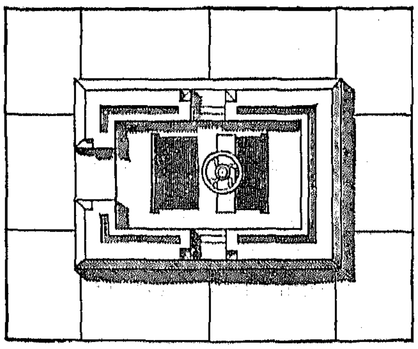
The influent gate-house at the Lawrence basin is the smallest of the three structures. It covers one gate that controls a connection between the aqueduct (which curves around one side of this part of the reservoir) and the basin. A short piece of brick aqueduct, 4 feet by 4 feet 4 inches, connects the two. A sewer is built to carry off the drainage of the valley, in order to keep it from entering the reservoir.

From the effluent gate-house a 48-inch main is carried around Fisher hill to connect with the pipes which supply the city from the Brookline reservoir, so that in case of any accident to that reservoir the city can be supplied from Chestnut hill. The length of this 48-inch pipe is about 1¼ mile. Its thickness is 1¼ inch. There are four gates at the junction of this pipe with the other mains; three, a 40-inch, a 36-inch, and a 30-inch connection, are together in one underground chamber; and a 48-inch gate on the main itself, which was put in in April, 1875, is a little back and separated from the chamber.

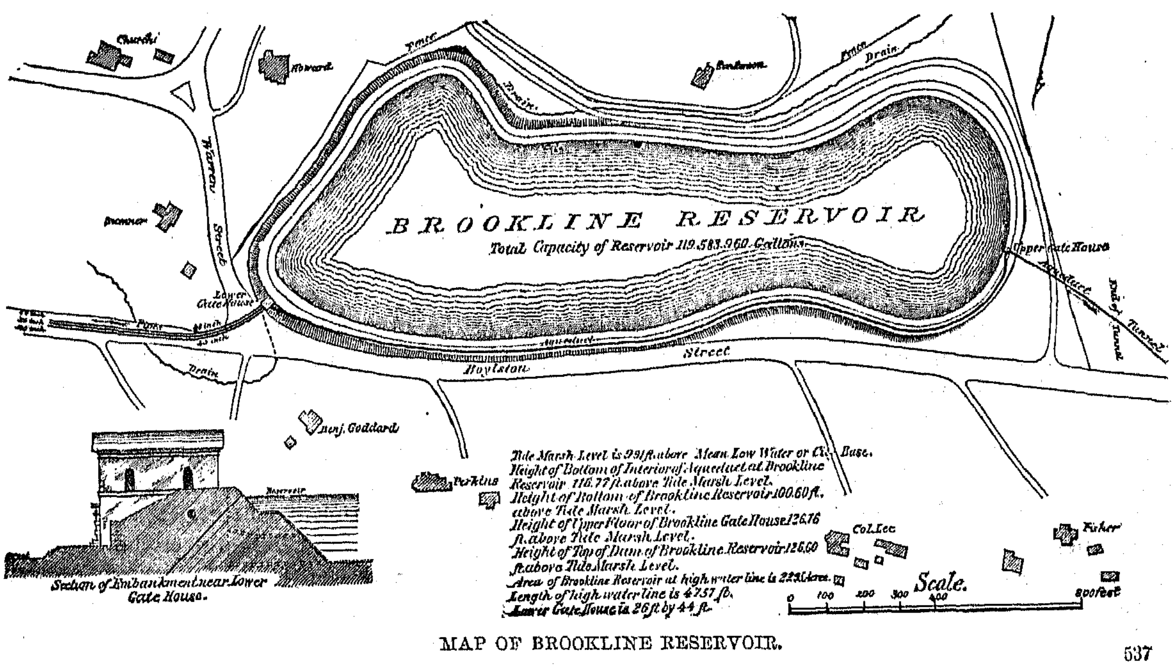


INFLUENT GATE-HOUSE AT CHESTNUT HILL RESERVOIR.

The Brookline receiving reservoir is situated at the eastern termination of the brick portion of the Cochituate aqueduct, in Brookline. It is formed out of a natural basin, inclosed almost entirely by banks rising to a considerable height above it. On the northerly side, however, there was no bank, consequently a puddled embankment was built up to a height of about 26 feet, and was supported by a retaining-wall 8 feet in height. The inner slope of the reservoir is lined with a slope-wall of granite rubble 18 inches thick and 14 feet broad, this lining rising to within 1 foot of the top of the bank. The greatest depth of water is near the principal gate-house, 24 feet. The least depth is near the upper gate-house, where it is about 14 feet. The embankment is 20 feet wide at the top, with a gravel walk all round. The area of the reservoir at a level of 6 feet below the top of the dam is 22.31 acres, and its capacity is 89,909,730 wine gallons, the contour of the water-line being 4,696 feet long. At 2 feet below the top of the dam it contains an area of 22.95 acres, and the capacity is 119,583,960 gallons; the contour of the water-line is, at this level, 4,757 feet. The reservoir is an irregular oval in shape.



Plan



MAP OF BROOKLINE RESERVOIR.

A cylindrical brick conduit is laid at a depth of 8 feet within the northern embankment, to connect with that from the lake, and conduct the water around the reservoir to the pipe-chambers, by means of which it was intended that the supply of the mains should be kept up when the water is shut off from the reservoir for cleansing it or for any other purpose.

There are two gate-houses, the upper for receiving the termination of the brick portion of the aqueduct, and the lower for the beginning of the iron main leading to the city, with regulating gates, gauges, etc.

The principal or lower gate-house has its front on the street, where it is 26 feet 4 inches wide by 36 feet 8 inches high, including the basement, which is 16 feet 4 inches. The height in the rear is 20 feet. Two iron stair-cases ascend from the basement to the main floor. The building is of hammered granite, with an iron roof. The main floor is on a level with the top of the embankment, and the bottom of the gates which regulate the admission of water into the pipe-chambers is 26 feet below the floor. The gates and gate-frames are of iron. There are three pipe-chambers into which the mains now laid are introduced, two only having been used until the year 1859, when the 40-inch main was laid over the mill-dam.

At the upper gate-house is the termination of the brick aqueduct, and it is fitted with stop-planks and a flap-gate for regulating the flow of water into the reservoir. The building is of granite, with a stone roof. The front is 11 feet 3 inches wide by 11 feet 4 inches high, and the length is 12 feet. The following are the heights, respectively, above tide-marsh level: Top of dam or embankment, 126.60 feet; upper floor of principal gate-house, 126.76 feet; low-water mark, 120.60 feet; bottom of interior of aqueduct, 116.76 feet; bottom of reservoir, 100.60 feet.

There were three distributing reservoirs constructed for the purpose of receiving the water from the mains leading from the Brookline reservoir during the latter part of the day and the night, when it was presumed but little would be drawn from the service-pipes, and of supplying it to the service-pipes in the morning, when the greater portion for domestic purposes was required; by which means a continuous supply could be kept up to a more uniform height. These distributing reservoirs were the Beacon Hill, South Boston, and East Boston.

It is now contemplated to remove or dismantle Beacon Hill reservoir and use the site for other purposes. It has not been in use since June 6, 1870, the high-service works at Roxbury supplying its object and the neighborhood for which it was especially constructed.

The high-service works at Roxbury has rendered the South Boston reservoir useless, and water has been shut off since July 15, 1872, but nothing has as yet been done regarding its ultimate disposal.

East Boston being now supplied from the Mystic department, the reservoir is shut off, but kept full of water in case of emergency.

The city is supplied from its distributing reservoirs by three iron mains, 36, 30, and 40 inches, respectively, in diameter, starting from the effluent gate-house of the Brookline reservoir.

When the gate-house was built an extra 30-inch outlet was provided, and, it being considered unsafe to remove it to substitute a 40-inch, the 40-inch main is connected with it, and on the taper connection there is a 20-inch inlet, now capped, which can be continued through the masonry bulkhead above the 30-inch if the supply be insufficient. After leaving the gate-house they pass into Boylston street, in an easterly direction to the city. A few hundred feet from the gate-house these mains connect with a 48-inch pipe leading from the Chestnut Hill reservoir. In a chamber near the road are three gates, each of which, by means of branches, connects the 48-inch pipe with one of the above mains, so that the supply from the Chestnut Hill may be cut off or let on as required from either of the mains. Between the Brookline reservoir and these connections there is a gate on the 30-inch pipe, to allow of the emptying of the Brookline reservoir without interfering with the supply from Chestnut hill.

The Beacon Hill district, comprising about 48 acres, and necessitating a high-service supply, is furnished with a 20-inch main, taking off the 24-inch main from the Parker Hill reservoir.

The South Boston low service is supplied by two 20-inch pipes. One of these, taking off from the 36-inch main, crosses the Fort Point channel at the Dover Street bridge; the draw is passed by a siphon, the distance between the arms of which is 41 feet. A trench was excavated into the hard bottom of the channel 32½ feet below the top of the bridge, and the siphon was laid in a box filled in with hydraulic cement. This main runs to the reservoir on Telegraph hill. The second 20-inch main leaves a 24-inch main in Dorchester and passes to the reservoir on Telegraph hill. The two mains connect at the corner of Atlantic and Thomas streets. The reservoir is not now used, as has been stated.

The South Boston high service is fed by a 12-inch pipe leaving the 20-inch high-service pipe in Boston proper at Berkeley street, and connects with the South Boston high-service pipes opposite the reservoir. This pipe crosses the Fort Point channel at the Dover Street bridge, with an inverted siphon. The siphon is made of 16-inch pipe, and is laid in a box surrounded by concrete.

The district of East Boston is supplied by a 20-inch main, which leaves the 24-inch main in Boston proper in Haymarket square. On its route to East Boston it crosses Charles river, over the Warren bridge, passing the draw by an inverted siphon having a dip of 36 feet and a distance between the arms of 39 feet. It continues through Charlestown, where it has two connections with the Mystic works, and crosses to Chelsea over the Chelsea bridge, where it passes under two draws. At the southerly draw the siphon dips 34 feet, with a length of 50 feet; at the northerly draw the dip is 42 feet 5 inches, and the distance between the arms is 50 feet. All the siphons are inclosed in wooden boxes and are protected with concrete. In Chelsea this main has two connections with the Mystic works. From Chelsea it passes to East Boston across Chelsea creek to Brooks street. The creek is crossed by means of flexible jointed pipe, 461 feet long. The flexible portion of the pipe was laid in a trench, dredged to about 6 feet in depth, and covered with clay and gravel to protect it. The creek itself is about 1,600 feet wide. The flexible joints were movable only in a vertical plane, and were adopted by Mr. William S. Whitwell, the engineer. In 1871 a new main, 24 inches in diameter, was laid across the creek, and was connected at each end with the 20-inch main. From Chelsea creek the main passes on to the reservoir, whence the distribution takes place through a 16-inch pipe.

This service is principally supplied from the 24-inch Dorchester main, leaving the 30- and 36-inch mains near the Boston and Providence Railroad crossing. One 12-inch branch leaves the 24-inch main also near the crossing, and passes through Roxbury by the side of the 24-inch main on its way to Dorchester.

The pumping-engines on Elmwood street take their supply through a 16-inch connection with the 24-inch main in Roxbury street. A 16-inch force-main through Elmwood, Gardner, and Center streets and Fort avenue leads to the stand-pipe. From this 16-inch a 24-inch pipe branches off at Center street to the Parker Hill reservoir.

Dorchester receives its supply from a 16-inch main leading from the stand-pipe, reducing to 12 inches, at which size the mains extend. This supply is derived from the 24-inch main before mentioned as passing through Roxbury, terminating at Dorchester avenue.

The Brighton low service is supplied by a 16-inch main connecting with the 40-inch pipe on Beacon street. This pipe crosses the Boston and Albany railroad in Brighton avenue by means of an iron bridge of two continuous plate girders, each 137½ feet long. The high service is temporarily supplied by means of two small pumps and a reservoir, drawing their supply from a low-service 12-inch pipe in Brighton. The force-mains are 12 inches and 8 inches, respectively, in diameter, and the supply-mains are 12 inches and 6 inches, respectively, in diameter.

The Boston system embraces the following districts or localities: Boston proper, Brookline, South Boston, East Boston, Roxbury, Dorchester, West Roxbury, Brighton, and such portions of Newton and Needham as contain pipe connected with the Boston works.

Exclusive of the above, and belonging to the Mystic department, but under the control of the Boston water-board, are Somerville, Medford, Charlestown, Chelsea, and Everett. These will be treated of in the space devoted to the Mystic department.

The maximum loss of head between the Brookline reservoir and the city is about 25 feet, which occurs only in sudden changes to very cold weather, and is due to waste from the service-pipes, to prevent freezing.

There have been used in Boston many kinds of hydrants, among which might be mentioned the Lowell, the Ballardvale, the Wilmarth—now known as the Boston—the Kingston, the Hooper, and, more recently, the Lowry. Those used to-day are comprised under the three heads of Lowry, Boston, and Post, and the majority in use are flush-hydrants.

The following table gives the number of hydrants set in Boston up to January 1, 1878:

Districts.	Lowry.	Boston.	Post.
City proper	420	874	10
South Boston	128	348	....
East Boston	99	185	6
Roxbury	651	103	13
Dorchester	553	42	34
West Roxbury	84	19	175
Brighton	57	13	116
Total, 3,939	2,001	1,584	354

The following statement shows the number of hydrants in use in the Mystic department up to 1881:

Districts.	Lowry.	Flush.	Post.	Total.
Charlestown	169	34	35	238
Chelsea	....	5	131	136
Somerville	3	26	253	282
Everett	1	....	68	69
Medford	....	5	5	10
Total	173	70	492	735

The most popular meter in Boston at the present time is the Worthington. It is giving general satisfaction. The sizes in use in this city range between $\frac{5}{8}$ inch and 4 inches, and in the total number of 1,082 there are 686 $\frac{5}{8}$-inch, 333 1-inch, 46 2-inch, 13 3-inch, and 4 4-inch.

A few of the class known as the Johnson meter are in use. This is a single-piston meter manufactured in Boston, and is comparatively new.

THE MYSTIC DEPARTMENT.

One of the factors in the Boston water-works system is the Mystic supply, once operated by a distinct management, and designed originally for the supply of Charlestown and Chelsea, the northeasterly suburbs of Boston proper.

On April 13, 1854, several gentlemen, interested in the Cambridge water-works, procured from the legislature the right to supply Charlestown with water, under the name of the "Charlestown Water Works". The increasing requirements of the city had made it evident that more energetic action was necessary, and in August, 1859, the city council authorized Mayor Dana to obtain a charter to supply the city with pure soft water. Messrs. George R. Baldwin and C. L. Stevenson were appointed engineers, and detailed scientific examinations were made of all the sources within 15 miles of the city. These resulted in the report that only Spot and Mystic ponds were available. Spot pond, from the favorable conditions belonging to it, in its elevation, position, and purity, has undergone more minute examination than any other source in the neighborhood.

In 1845, Mr. J. B. Jervis, engineer of the Croton water-works, and W. B. Johnson, civil engineer, having been appointed water commissioners for Boston, found the yield of Spot pond to be 1,500,000 gallons per day, derived from a drainage area of 1,100 acres, the extreme elevation of the pond accounting for the limited drainage area.

Mystic lake, from the upper or northerly portion of which the supply is taken, is located in the towns of Medford, Arlington, and Winchester, 6⅗ miles from Charlestown square. At the level of flowage authorized, it has an area of about 200 acres, with a storage capacity of 380,000,000 gallons of water. The area of the drainage basin of the Mystic lake is 27.5 square miles. The numerous ponds in the basin serve to check the too-rapid discharge of the rainfall into the lake and thence into the river; but, nevertheless, the discharge is rapid. The geological characteristics of the basin are, that the greater part of its length and breadth is composed of a deposit of gravel and sand of a considerable depth, underlaid with primitive trap of the common greenstone variety, which crops out on the hills occasionally.

From the report of the chief engineer, published in 1865, we note his estimate of the safe daily available yield of Mystic lake to be 30,000,000 gallons.

The following table gives the rainfall and approximate quantity of water daily consumed from the Mystic works since 1866:

Year.	Total yearly rainfall.	Approximate daily quantity of water consumed.	Remarks.
	Inches.	*Gallons.*	
1866......	40.48	1,000,000	
1867......	42.10	1,300,000	Extended to Chelsea.
1868......	40.12	1,000,000	Extended to Somerville.
1869......	37.71	2,500,000	
1870......	24.65	4,000,000	Water let on to East Boston.
1871......	24.84	5,000,000	Extended to Everett.
1872......	45.71	6,800,000	
1873......	48.60	7,700,000	
1874......	34.14	7,600,000	57,000,000 gallons supplied, in all, to Boston.
1875......	48.06	7,500,000	East Boston shut off from April 21 to December 2.
1876......	47.00	8,825,000	
1877......	41.60	8,378,000	

The rainfall was measured at Mystic lake.

The Mystic valley, besides containing a large population within its limits in the form of small towns or otherwise, whose sewage up to the present must in large part have naturally found its way to the lower levels, is the site of some 82 factories—more than a third of which are tanneries—employing some 3,500 hands. The refuse from this large manufacturing interest, situated as the tanneries must be, on the banks of the streams, also finds its way into the lake.

Professor E. N. Horsford, of Cambridge, in his report on the analysis of the Mystic water in 1873, says: "Of its salubrity as a drinking-water, it will compare well with the best waters in use for city supply. It has experienced no appreciable deterioration since its introduction."

The Mystic system comprises: Dam and overfall; conduit, gate-houses, waste-weir, etc.; cast-iron mains under Mystic river, bridge, etc.; engine-house and pump-well; pumping-engines; force-main; reservoir and appurtenances; supply-main and city distribution. A detailed description may be found in the report of 1874, before mentioned. The pumping machinery only will be here mentioned.

The pumping-engines in the Mystic pump-house are of the Worthington make, three in number, two of 5,000,000 and one of 8,000,000 gallons capacity. One of the former was erected in 1865, the other in 1866, and the third in

1872. The diameter of the steam-cylinders of the former are 43.3 inches for the low and 25 inches for the high pressure. Length of stroke, 48 inches.

Of the 8,000,000-gallon engine, the low-pressure cylinder is 50.25 inches and the high pressure 29 inches diameter. The average velocity is 44 strokes per minute. The smaller engines have plungers 22 inches in diameter with 48-inch stroke, and the larger 28 inches in diameter with 50-inch stroke. These engines are driven by a set of horizontal multitubular boilers 16 feet long by 5 feet 3 inches in diameter, containing eighty 3-inch tubes in each, and fired at a pressure of 45 pounds. With the Cumberland coal used they evaporate 10.2 pounds of water per pound of coal.

The force-main is 3,277 feet in length. The level of this main at the engine-house is 16 feet 6 inches above tide-water, and it rises gradually to the reservoir, in which the level of high water is 147 feet above tide-level.

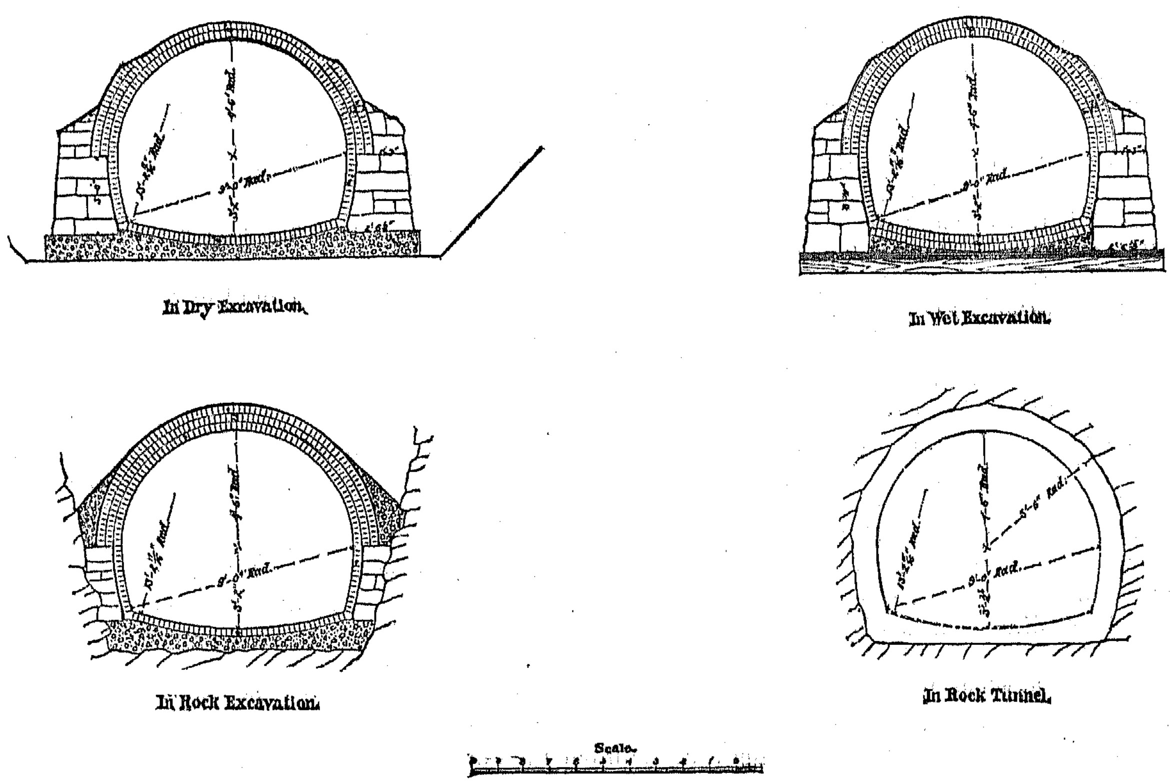
ADDITIONAL SUPPLY OF WATER.

The additional supply of water is derived from Sudbury river, a stream of moderate size, which flows in the towns of Westboro', Ashland, Framingham, Wayland, Sudbury, and Concord, in the state of Massachusetts. It flows in a general northeasterly direction, and meets, in the town of Concord, the Assabet river. Both streams then join to form the Concord river, which flows into the Merrimack river at Lowell.

The city diverts the water from Sudbury river in the town of Framingham, at a point where the available water-shed is $74\frac{2}{3}$ square miles in area.

The calculations for the supply of the city are based upon an annual yield, in a dry year, of a quantity of water corresponding to a depth of 12 inches on the whole water-shed.

It has been calculated that seven reservoirs would be necessary, with a capacity of 4,900,000,000 gallons, to give to the city, in the driest year, a permanent supply of 40,000,000 gallons per day. Such an amount of water not being required at present, three reservoirs only, of a capacity of 2,000,000,000 gallons, are being constructed, which will be sufficient to secure to the city, in the driest weather, a supply of 20,000,000 gallons per day.



SUDBURY RIVER CONDUIT.

From the lower reservoir on the river the water is conducted through a brick aqueduct into Farm pond, a natural pond of 200 acres, used as a settling reservoir. From Farm pond the water is drawn into the main conduit, 16 miles long, which carries it through the towns of Framingham, Sherborn, Natick, Needham, and Newton into Chestnut Hill reservoir. This reservoir, already described, receives the present supply from lake Cochituate, and is connected with the pipe-distribution of the city.

The various parts of the work on the "additional supply" are either finished or in course of construction, and the water of Sudbury river is sent into the city. For description of the reservoirs and dams, see description of Boston water-works, above mentioned.

At the southeast corner of Farm pond is placed the gate-chamber, which contains the head of the main conduit. It is provided with two sets of large sluice-gates, 4 by 6 feet. Its foundation is on piles, as is the foundation of the beginning of the conduit in Farm pond. After leaving Farm pond the conduit passes to Chestnut Hill reservoir. Its total length is about 16 miles.

For convenience of description, reference will be made to the stations on the line enumerated in the following table. Stations are 100 feet in length:

Section.	Station.	To station.	Total length.
			Feet.
1	0	6	600
2	6	51+50	4,550
3	51+50	114+50	6,300
4	114+50	155+70	4,120
5	155+70	190	3,430
6	190	220	3,000
7	220	284+25	5,525
8	284+25	315+55	3,130
9	315+55	381	6,545
10	381	388	700
11	388	432	4,400
12	432	509	7,700
13	509	561+50	5,250
14	561+50	623	6,150
15	623	639	1,600
16	639	684	4,500
17	684	730	4,600
18	730	737	700
19	737	773+22	3,622
20	773+22	To end.	About 1 mile.

Total length, about 16 miles.

On section 2, station 34+67, Beaver Dam brook, the chief feeder of lake Cochituate, passes under the conduit by a large siphon culvert.

At station 112 the line crosses Course brook, another feeder of lake Cochituate. At this point a waste-weir is constructed, to empty the conduit, if necessary, and from which the waste-water finds its way into the lake.

On section 7, station 271+40, the second waste-weir was built. This brook empties into the Charles river.

Section 8 includes the Badger Hill tunnel, 1,575 feet long.

Section 10 is the Waban Brook bridge. The bridge is formed of 9 semicircular arches, 44 feet 8 inches span, built of Maine granite, with a brick parapet and iron railing. The bridge is 536 feet long. The valley is about 40 feet deep and 2,000 feet long. The line as located passes through a small knoll, and the conduit is carried over the remaining portion of the valley in an embankment, in section 11, 30 feet high and 1,200 feet long. The excavation on section 11 is largely in hard pan and rock. A cut in this section was at its deepest 35 feet, while 600 feet of it was 15 feet deep.

On section 12 Fuller's waste-weir is constructed.

On section 13 comes the Rosemary Brook siphon; the valley, crossed in its narrowest point, is about 1,800 feet wide. It is to be crossed by three lines of 48-inch pipe, only two of which are at present laid. The channel of the brook is covered by an arch culvert 10 feet in diameter, and the pipes are here furnished with blow-offs.

Section 15 comprises principally the Charles River bridge, 11.8 miles from Farm pond, and the most important structure on the line. Its length is 475 feet between the chambers at the ends of the bridge.

The section adopted for the conduit is equivalent to a circular section of 8½ feet in diameter, and in ordinary conditions of cleanliness will deliver at the rate of 70,000,000 gallons in 24 hours, when flowing at the assumed water-line.

Throughout the whole length of the conduit, manholes are provided, about 1,500 feet apart. The arch and interior lining are of brick, and the side-walls of rubble-stone masonry. The conduit terminates in a large chamber located at the Chestnut Hill reservoir. From that chamber the water from Sudbury river is distributed as follows, each pipe being provided with a sluice-gate: One 48-inch pipe is connected with one of the divisions of the Chestnut Hill reservoir, one 60-inch pipe is connected with the other division of the Chestnut Hill reservoir, one 48-inch pipe with the Cochituate aqueduct. Another 48-inch pipe is laid around the Chestnut Hill reservoir, and is connected, independently of it, with the city pipes. Room has also been provided for a duplicate of this pipe, which will be laid when the increase in the consumption of water shall render it necessary.

The report on the Boston water-works of 1874, already referred to, gives, in table 111, the amount of rainfall, consumption, etc., from 1852 to 1874.

The total cost of the works to May 1, 1880, is $16,341,908 for the Cochituate water-works and $1,614,648 for the Mystic works.

The expenses for maintenance and repairs of the Cochituate works for the year ending May 1, 1880, amounted to \$171,160; of the Mystic works, \$96,079. Total, \$267,239.

The cost of the works for "additional supply", up to October 1, 1880, was \$5,234,678, with land damages of \$543,190.

The Roxbury high service comprises engine-house, 3 pumping-engines, force-main, stand-pipe, Parker Hill distributing reservoir, and distribution mains.

The engine-house, located on Elmwood street, is a plain brick building 40 feet wide, comprising, with the boiler-house and coal-shed, a space of 5,563 square feet. It contains two high-pressure, horizontal, direct-acting engines, built by the Boston Machine Company in 1870, and driving two double-acting pumps. Their capacity is 2,400,000 gallons per day each; diameter of pump-cylinders, 14 inches; diameter of steam-cylinders, 20 inches; stroke, 36 inches; diameter of fly-wheels, 15 feet; number of revolutions per minute, 25; duty, 30,000,000 foot-pounds. The steam-valves are double-seat puppet-valves, operated by four cams, connected by spur and bevel gearing with the main crank-shaft. The cost of the two engines, with boilers, is stated at \$37,500.

Steam is supplied to each engine from a vertical multitubular boiler 7 feet in diameter and 13 feet high, with $2\frac{1}{2}$-inch tubes, 10 feet long, at a pressure of 60 pounds per square inch. Their evaporative power is estimated at 11 pounds of water per pound of anthracite coal, and the details may be seen in the appended table for 1879:

1879.	Engine No. 2.			Worthington engine.			Total amount pumped by both engines.	Daily average amount pumped.	Total amount of coal consumed.	Daily average amount of coal consumed.	Ashes and clinkers.	Quantity pumped per pound of coal.	Average lift.	Duty per 100 pounds of total coal by Worthington engine.
	Total pumping time.		Total amount pumped.	Total pumping time.		Total amount pumped.								
	Hrs.	*Min.*	*Gallons.*	*Hrs.*	*Min.*	*Gallons.*	*Gallons.*	*Gallons.*	*Pounds.*	*Pounds.*	*Per cent.*	*Gallons.*	*Feet.*	*Ft. pounds.*
January	......	......	....	651	......	70,860,000	70,860,000	2,560,000	150,400	4,852	12.7	527.7	118.04	51,946,100
February	......	......	....	588	......	67,084,000	67,084,000	2,395,857	122,900	4,389	11.5	545.8	115.27	52,474,200
March	......	......	....	651	......	69,083,500	69,083,500	2,228,500	124,200	4,006	11.6	556.2	112.04	51,972,400
April	......	......	....	633	......	60,357,000	60,357,000	2,011,900	106,500	3,550	12.7	556.7	109.96	51,971,200
May	7	30	443,210	636	55	67,704,000	68,147,210	2,198,297	120,700	3,894	13.0	563.3	111.11	52,659,000
June	......	......	....	630	......	70,339,000	70,339,000	2,344,633	124,000	4,133	13.0	567.3	110.88	52,455,800
July	......	......	....	644	52	69,400,000	69,400,000	2,239,000	129,000	4,161	15.1	539.5	113.65	51,122,800
August	......	......	....	650	......	72,044,000	72,044,000	2,324,000	133,600	4,310	14.7	538.0	116.89	52,460,000
September	......	......	....	630	......	66,371,000	66,371,000	2,212,367	126,100	4,203	15.3	526.3	117.35	51,511,000
October	......	......	....	651	......	66,185,000	66,185,000	2,135,000	121,700	3,926	14.3	543.8	116.66	52,910,100
November	......	......	....	630	......	63,550,000	63,550,000	2,118,333	118,800	3,960	13.1	534.9	116.19	51,837,700
December	......	......	....	651	......	68,897,500	68,897,500	2,222,500	132,700	4,281	13.4	519.2	118.04	51,113,000
Averages and totals	7	30	443,210	7,646	47	820,384,000	820,827,210	2,248,842	1,510,500	4,138	13.4	543.4	114.81	52,057,100

The capacity of these two engines combined is equivalent to about 4,800,000 gallons.

In 1877 a Worthington duplex engine was erected, of a capacity of 3,000,000 gallons per day, and since that time it has done most of the pumping with an economy shown by the following table. The stroke is 38 inches; diameter of steam-cylinders—high pressure, 21 inches, low pressure, 36 inches; diameter of pump-plungers, $17\frac{1}{2}$ inches; number of strokes per minute, about 48. The boiler used is similar to those just described, but generates steam at a pressure of 35 pounds.

The following statement shows the cost of pumping:

Salaries	\$3,743 96
Fuel	3,714 29
Repairs	2,206 60
Oil, waste, and packing	255 01
Gas and small supplies	358 80
Total	10,278 66

The cost of pumping 1,000,000 gallons 1 foot high in each year since the high-service works have been in operation is as follows:

1871	\$0 37	1875	\$0 22
1872	34	1876	18
1873	$28\frac{3}{10}$	1877	$13\frac{7}{10}$
1874	$24\frac{4}{10}$	1878	$12\frac{2}{10}$

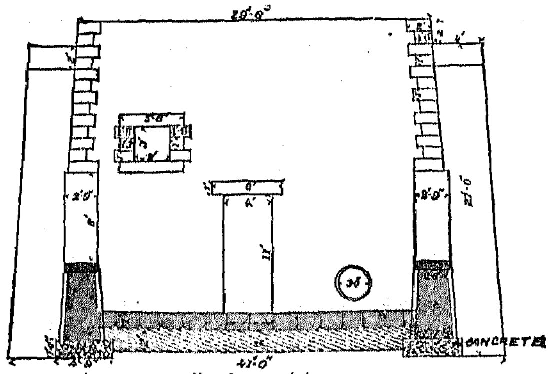
The supply to these pumps is through a 16-inch main connected with the Cochituate system under a head of 33 feet, and the average lift is 114 feet.

From the engines the 16-inch mains join and extend as a 16-inch main 2,500 feet to the stand-pipe, where the water can be diverted around the latter and direct into the mains if desired.

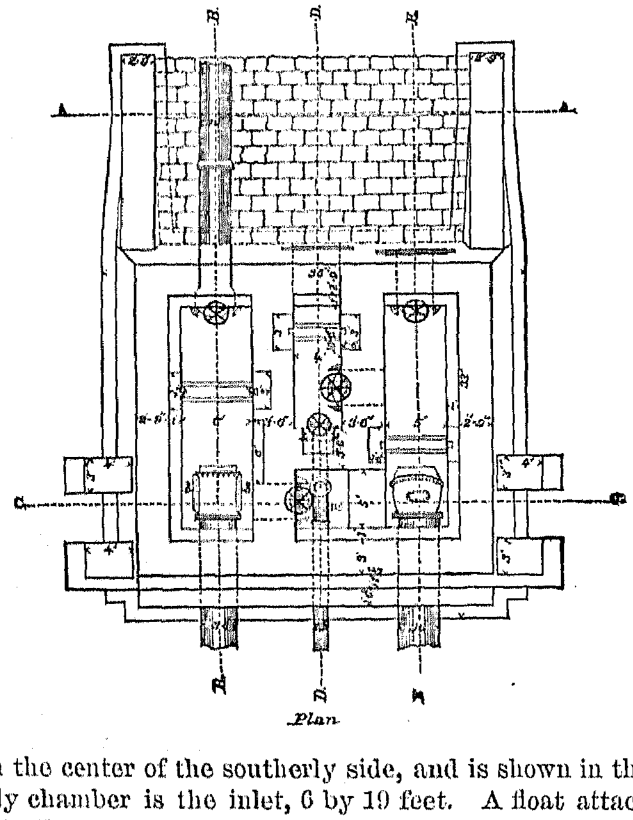
The stand-pipe is of boiler-iron, 5 feet in diameter and 80 feet high. A spiral staircase 3 feet wide extends to the summit, and the whole is inclosed in a brick tower, trimmed with granite and painted white, 15 feet in diameter at bottom and 13 feet at top.

THE PARKER HILL DISTRIBUTING RESERVOIR.

In case of accident to the pumps it was necessary to have a supply on hand, and hence the construction of this reservoir. From the 16-inch force-main near the stand-pipe a 24-inch branch is taken off leading to this reservoir. Its location is about 3 miles from the state-house. It is nearly rectangular in plan, 290 feet at the north and south sides, 196 feet at the east, and 253 feet on the west ends at the level of the top of the banks. The latter slope $1\frac{1}{2}$ to 1 inside and $1\frac{3}{4}$ to 1 outside; capacity, 7,200,000 gallons; area of high-water surface, 1.47 acre; depth, 22 feet at sides and 24 feet at center. It was built on a soil composed of a hard clay; gravel and 2 feet of clay puddle were spread upon it. The banks were lined with the same, upon which were laid 8 inches of broken stone and a paving 16 inches thick of stone, the surface of which is pointed in cement. The width of banks is 22 feet, and they are finished off with a flagged walk 5 feet wide.



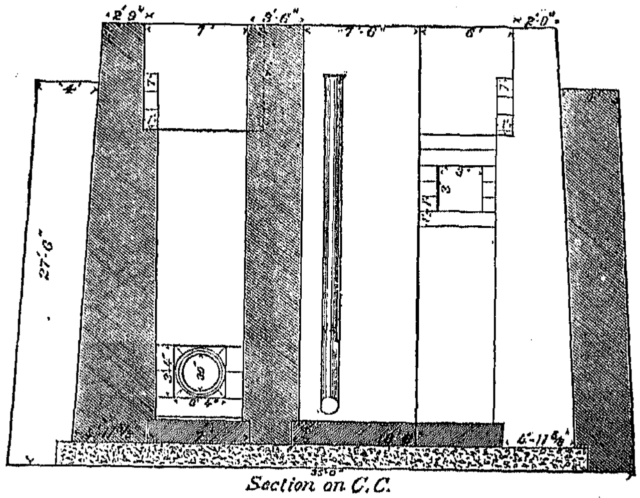
Section on A.A.



Plan

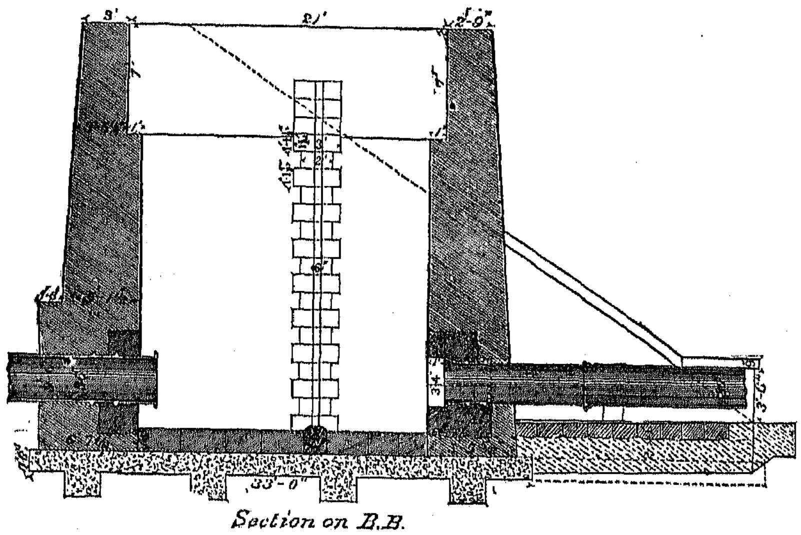
The gate-house is nearly in the center of the southerly side, and is shown in the cut, together with details and dimensions. The most westerly chamber is the inlet, 6 by 19 feet. A float attached to the inlet-pipe (36 inches in diameter) regulates automatically the height of the water. Between the float and the reservoir side of the chamber is a set of grooves, 6 inches wide, for stop-planks. The discharge-pipe, 30 inches in diameter, leaves this inlet-chamber and continues to the center of the reservoir, where it discharges upon a stone apron. It is partly shown in plan.

The outlet-chamber is 6 by 21 feet at the floor-level. The 36-inch outlet pipe is near the bottom. A 12-inch iron drain-pipe passes through this chamber. It is provided with two small iron gates to drain the chambers. It rises vertically to high-water mark, is open at top, and 23 feet above the paving of the floor of the chamber. One

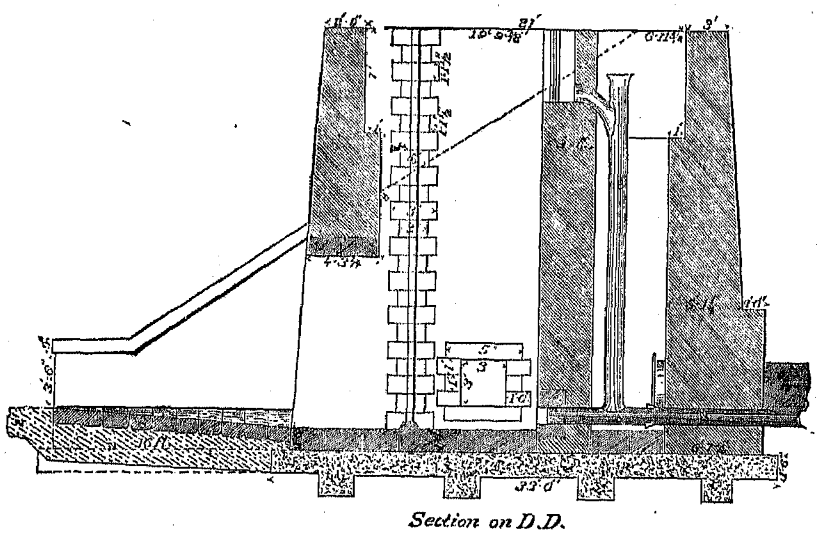


Section on C.C.

gate, 3 feet square, opens from the reservoir to the outlet-chamber at a height of 14 feet above the bottom. Another 3 feet square and 18 inches above the botton connects this chamber with the drain-chamber.

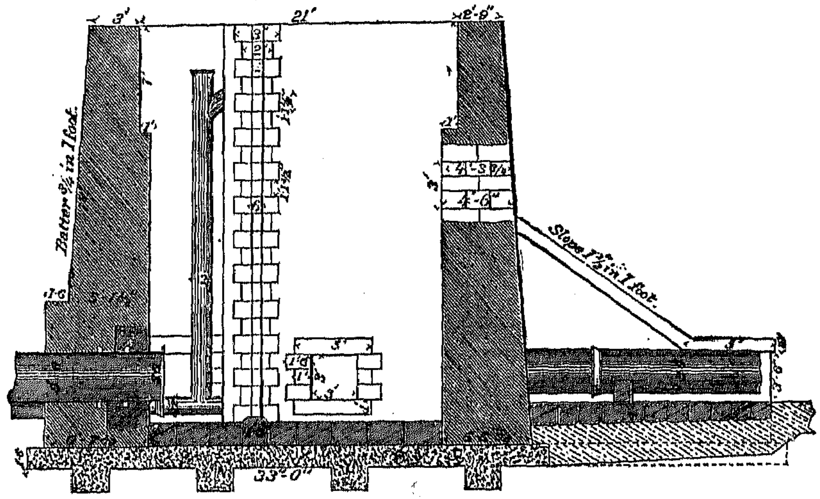


Section on B.B.



Section on D.D.

It may be well to explain that the gate-house is divided below the floor-level into the three chambers mentioned, viz. outlet-, inlet-, and drain-chambers. The last-named is 4 by $11\frac{1}{2}$ feet at floor-level, has a rectangular opening into the reservoir 4 by 11 feet, the bottom of which is on a level with the bottom of the chamber. The cuts in section show BB as the inlet-, DD the outlet-, and EE the drain-chamber. The cost of the reservoir, exclusive of land damages, was $141,317.



Section on E.E.

The analyses of the waters from the Mystic works are appended. The samples were drawn from the service-mains in each case, and the analyses were made at the Massachusetts Institute of Technology:

Locality.	Date.	Organic carbon.	Organic nitrogen.	Sum of the organic elements.	Ratio of carbon to nitrogen.	Ammonia.	"Albuminoid ammonia."	Total solids.
	1880.							
Charlestown	January 1	0.315	0.046	0.361	6.8	0.012	0.013	9.9
Do	January 15	0.313	0.054	0.367	5.8	0.012	0.011	10.2
Mystic pond	January 30	0.335	0.043	0.378	7.8	0.053	0.010	10.9
Charlestown	February 5	0.375	0.066	0.441	5.7	0.025	0.018	*11.0*
Mystic pond	February 6	0.401	0.095	0.496	4.0	0.040	0.023	11.4
Charlestown	February 12	0.442	0.060	0.502	7.4	0.037	0.018	11.4
Mystic pond	February 17	0.471	0.057	0.528	8.3	0.025	0.021	8.8
Charlestown	February 19	0.421	0.044	0.465	9.6	0.035	0.020	10.1
Do	February 26	0.346	0.039	0.385	8.9	0.031	0.016	*10.4*
Do	March 4	0.347	0.039	0.386	8.9	0.033	0.016	9.9
Mystic pond	March 6	0.349	0.040	0.389	8.7	0.044	0.017	10.3
Charlestown	March 11	0.356	0.062	0.418	5.7	0.027	0.016	9.7
Do	March 19	0.314	0.060	0.374	5.3	0.027	0.013	9.9
Do	*March 25*	0.322	0.062	0.384	5.2	0.027	0.015	*10.4*
Do	April 1	0.309	0.045	0.354	6.9	....	....	10.3
Mystic pond	April 5	0.273	0.046	0.319	5.9	0.040	0.016	10.1
Charlestown	April 9	0.297	0.044	0.341	6.8	0.024	0.015	10.7
Mystic pond	April 14	....	....	....	....	0.041	0.017	10.2
Charlestown	April 15	0.361	*0.054*	0.415	6.7	0.020	0.017	*10.5*
Do	April 22	0.297	0.060	0.357	4.9	0.013	0.016	10.8
Do	April 29	....	....	....	....	....	....	10.4
Mystic pond	May 3	0.386	0.061	0.447	6.3	0.037	0.020	10.2
Charlestown	May 6	0.256	0.054	0.310	4.7	0.007	0.017	10.7
Mystic pond	May 12	0.366	0.082	0.448	4.4	0.031	0.021	*10.5*
Charlestown	May 13	0.333	0.068	0.401	4.9	0.008	0.016	10.9
Do	May 20	0.359	0.073	0.432	4.9	0.008	0.016	10.5
Mystic pond	May 24	0.332	0.045	0.377	7.4	0.031	0.021	10.6
Charlestown	May 27	0.358	0.061	0.419	5.9	0.009	0.021	10.8
Charlestown, mean of 35-39 samples	June, 1879, to May, 1880	0.392	0.065	0.457	6.0	0.012	0.018	*9.9*
Mystic pond (surface), mean of 12-14 samples	October, 1879, to May, 1880	0.349	0.054	0.403	6.5	0.028	0.018	10.0
Charlestown, mean of 19-20 samples (*a*)	October, 1879, to May, 1880	0.339	0.053	0.392	6.6	0.019	0.015	9.8

a This average is made up from the samples drawn in Charlestown.

The analyses of the Boston water by the same authority were made of water drawn from the service-pipe in the Institute of Technology, as follows:

Date.	Temperature in centigrade degrees.	Organic carbon.	Organic nitrogen.	Sum of the organic elements.	Ratio of carbon to nitrogen.
1880.					
January 1	3.3	0.500	0.055	0.555	9.0
January 16	3.3	0.545	0.064	0.609	8.5
January 28	....	0.694	0.064	0.758	10.8
January 31	3.0	0.614	0.041	0.655	15.0
February 5	2.9	0.659	0.061	0.720	10.8
February 9	4.0	0.668	0.072	0.740	9.3
February 12	....	0.723	0.063	0.786	11.5
February 19	3.0	0.592	0.051	0.643	11.6
February 25	3.1	0.526	0.064	0.590	8.2
March 4	6.3	0.582	0.047	0.629	12.4
March 11	4.2	0.443	0.071	0.514	6.2
March 18	6.8	0.413	0.060	0.473	6.9
March 26	4.2	0.438	0.037	0.475	11.8
April 1	4.8	0.368	0.046	0.414	7.9
April 9	....	0.446	0.048	0.494	9.3
April 16	9.2	0.397	0.044	0.441	9.0
April 22	9.8	0.360	0.047	0.407	7.7
May 6	13.2	0.325	0.046	0.371	7.1
May 13	15.6	0.361	0.063	0.424	5.7
May 21	15.8	0.423	0.034	0.457	12.4
May 28	18.8	0.447	0.075	0.522	6.0
Mean of 42 samples	....	0.452	0.051	0.503	8.9

The daily consumption for 1880 averaged 26,500,000 gallons, and frequently reached a maximum of 40,000,000 gallons.

The total number of hydrants is divided about as follows:

Boston	1,325	Deer island	16
South Boston	486	Brookline	6
East Boston	297	Charlestown	3
Boston Highlands	788	Chelsea	8
Dorchester	683		
West Roxbury	323	Total	4,144
Brighton	207		

The following table gives the total length of mains laid to May, 1880:

	DIAMETER OF PIPES IN INCHES.															Aggregate.
	60	48	40	36	30	24	20	16	12	10	9	8	6	4	3	
Feet of pipe laid in Brookline, Boston Highlands, and Boston proper	....	7,283	23,166	20,070	26,770	5,773	5,823	20,160	116,721	....	656	33,880	324,781	94,605	....	
Number of stop-cocks in same	..	6	6	8	11	11	9	45	254	....	....	105	877	416	....	
Feet of pipe laid in Boston Highlands	....	....	....	185	100	11,427	6,200	12,130	87,226	....	916	7,167	164,706	20,314	238	
Number of stop-cocks in same	....	....	....	1	2	9	4	21	130	....	....	15	361	120	2	
Feet of pipe laid in South Boston	....	....	....	....	....	....	13,206	....	47,564	....	105	5,156	120,331	37,170	....	
Number of stop-cocks in same	....	....	....	....	....	....	6	....	77	....	....	9	248	112	....	
Feet of pipe laid in East Boston	....	....	....	....	....	1,463	15,972	2,152	36,715	9,923	218	23,074	86,841	6,511	....	
Number of stop-cocks in same	....	....	....	....	....	....	8	5	45	3	....	15	154	55	....	
Feet of pipe laid in Dorchester	....	....	....	....	....	7,784	3,698	456	105,970	....	1,340	27,752	110,416	4,331	....	
Number of stop-cocks in same	....	....	....	....	....	5	2	1	125	....	....	42	237	26	....	
Feet of pipe laid in West Roxbury	....	....	....	....	....	....	10	2,916	72,199	....	....	37,318	47,275	1,452	....	
Number of stop-cocks in same	....	....	....	....	....	....	....	1	69	....	....	45	95	14	....	
Feet of pipe laid in Brighton	....	....	....	....	....	....	....	8,975	42,697	....	....	21,772	22,173	520	....	
Number of stop-cocks in same	....	....	....	....	....	....	....	5	58	....	....	32	52	8	....	
Feet of pipe laid in Newton, Needham, and Chestnut Hill reservoir, Framingham	266	16,051	1,435	1,111	2,140	....	....	20	2,048	....	....	....	360	....	....	
Number of stop-cocks in same	....	....	....	2	....	....	....	2	4	....	....	....	2	....	....	
Total length of pipe laid, in feet	266	23,334	24,601	21,366	21,010	26,447	44,909	46,809	511,165	9,923	3,234	156,119	804,883	173,903	238	1,966,216
Number of stop-cocks put in	....	6	6	11	13	25	29	80	762	3	....	263	2,026	755	2	3,981

The water-works of Boston are under the control of the present city engineer, Henry M. Wightman, and W.

HARTFORD, CONNECTICUT.

Hartford contains a population of 42,015 inhabitants, and is situated on the Connecticut river, about 40 miles, in a direct line from Long Island sound. Its business interests are largely mercantile and manufacturing. It is situated upon a succession of ridges of land running north and south. The first of these ridges rises from the river for a distance of a few blocks to the principal street, and thence it falls for several blocks to the tracks of the New York, New Haven, and Hartford railroad; crossing these, the land again rises rather sharply toward the west, forming Asylum hill, upon which the distributing reservoir is located. The ridges mentioned are also intersected in the southern portion of the city by a narrow strip of lower land.

Water was first introduced into the city in 1855, and is owned and managed by the city. The largest part of the supply is derived by gravity from a number of small streams in West Hartford and Farmington, about 5 miles west of the city, known by such names as Trout brook, Mine brook, Cadwell brook, etc., having a total drainage area of about 9.58 square miles, and situated among the hills at an elevation above the Connecticut river of 260 feet to the level of high water in the first or oldest reservoir. In addition to this gravity supply there is an auxiliary supply from the Connecticut river to certain portions of the city during dry weather, by pumping machinery on the west bank of the river in the upper part of the city. The pumping is direct into the mains, and a pressure is produced equivalent to 125 feet head.

In 1866 the pumping-works which furnished the original supply were supplemented by an additional supply from the first new reservoir on Trout brook, in West Hartford, which had been begun in 1865, and completed at a cost of about $200,000, including supply-pipe, damages, etc.

This reservoir, located on Trout brook, and known as No. 1, as detailed by the commissioners in 1867, flows, when full, 32 acres, and has a capacity of 156,600,000 gallons. The dam has a total height of 53 feet, rising 6.3 feet above the top of the water, and is 782 feet long. As already stated, the high-water surface is 260 feet above mean high water in the Connecticut river. The dam is 27 feet wide at the top; slope, 3 to 1 on the inside and 2 to 1 on the outside. A puddle-wall extends from 3 feet above high-water mark, where it is 4 feet thick, downward through the center of the dam to the base, where it is bedded in the rock and is 25 feet thick. Three 20-inch mains, one as a waste-pipe, pass through the base of the dam. It was partially destroyed by a freshet. The above is the condition now existing. It was planned by William J. McAlpine, civil engineer. The waste-weir is 42 feet long.

Reservoir No. 3 is located on Mine brook, and about one-tenth of a mile north of No. 1. It flows an area of 44 acres, has a capacity of 283,694,375 gallons, and was built in 1868. The dam is built upon a foundation of rock, and is constructed of earth, with a puddle-wall similar to that of No. 1. Its width at top is 27 feet, and its total length 1,300 feet. It extends 5 feet above high-water line, has an interior slope of 3 to 1, covered with a wall of riprap. The exterior slope is 2 to 1, and the extreme height of the dam is 42 feet. The maximum depth of water is 33 feet. One 20-inch and one 16-inch pipe are laid through the base of the dam. This reservoir, though called No. 3, was the second one built. Its waste-weir is 56 feet in length.

The storage capacity of these two reservoirs being insufficient for the purposes of the city, a third one was built, and completed in 1875, known as No. 4. It is located about 1 mile northwest of No. 1, on a branch of Trout brook, in a valley bordered by considerable hills of trap-rock, and on cleared and grubbed woodland. As described in the reports of the commissioners, the following dimensions, etc., are given:

The bottom trench was cut 25 feet in width to rock, at a depth of 19 feet below the bed of the stream. Above this the earth dam was built to a height of 42½ feet above the bed of the stream, with a core of puddle, as in the other two already described. The length at the bottom is 170 feet, at the top 560 feet. Extreme width at the base, 225 feet; at the top, 30 feet, and at high-water line, 50 feet. The dam rises 5 feet 6 inches above high-water line. The interior slopes 3 to 1, the exterior 2 to 1, with a riprap facing 30 inches deep, of stone.

A waste-way 25 feet wide was constructed about 700 feet above the dam on the eastern shore, and passes around the end at a distance of about 100 feet from it, discharging into the stream 300 feet below the dam. Two discharge-pipes are built through the base at the former level of the stream—one 20 inches and the other 16 inches in diameter, both laid in a puddle-wall and protected by screens. A dike 310 feet long by about 5 feet deep has been built at the northern end of the reservoir to prevent the escape of water into Mine brook. Another dike 125 feet long by 4 feet deep prevents escape into the southerly section of reservoir No. 3, which is 6 feet below it in level. A 12-inch pipe connects reservoirs 3 and 4. These dikes have a facing of riprap as in the main dam.

The area of land overflowed by the reservoir at high water is 25.42 acres, and contains at that stage about 154,524,800 gallons. The whole cost of construction was $59,117. Average length 2,890 feet, and average width 380 feet.

Reservoir No. 2 has never been completed, but is described in the report of 1880.

The distributing reservoir is situated on Asylum hill, in the western portion of the town. It is an earth-embankment reservoir, 380 feet long by 180 feet wide at the level of the top of banks, and 360 by 168 feet at water-line. The total depth to high-water surface is 30 feet.

The embankments have a puddle-wall running through the center, the dimensions of which can not now be ascertained, as no drawings exist. The slope of the banks is 1 to 1 inside and 1½ to 1 outside. The inner face is riprapped with stone laid dry. The total capacity is 10,000,000 gallons.

The gate-house surmounts a chamber containing two compartments, and is 20½ by 22 feet. There are two supply-mains and one force main, and an 8-inch waste-pipe from the chambers. The force-main is 16 inches, one supply-pipe is 12 inches, and the other 8 inches in diameter. This reservoir is gradually falling into disuse. In April, 1879, the east and west banks gave way, emptying the basin and permanently weakening the banks, since which time but 25 feet of water has been retained in it, solely to prevent internal collapse. The slope of the inner face had evidently been made too abrupt for the materials used.

In addition to the gravity system already described, the pumping-machinery is employed as auxiliary during the summer months, and for a short time in the winter when the supply is short and consumption at its maximum. It consists of a beam-engine of the ordinary river-steamboat type, driving, by means of gear-wheels, a set of four plunger pumps, forcing the water directly into the mains. It was constructed by Messrs. Woodruff & Beach, of the Hartford Machine Company, in 1873. One set of machinery erected in 1855 had been removed. The engine is condensing; cylinder, 34 inches diameter; stroke, 5 feet; is run at about 40 revolutions per minute. The puppet-valves are operated by a cam-shaft with plug-rods, and a Wright's cut-off is employed.

The condenser is of the jet type. Air-pump, 21 inches diameter by 2 feet 10 inches stroke. The cost of the engines and pumps together is said to have been $18,244. The steam is supplied by one drop-flue boiler, with two tubes of about 16 inches diameter. It is 8 feet 7 inches in diameter by 22 feet long. The usual pressure is about 20 pounds, with a consumption of 4 tons of anthracite per 24 hours, and pumping about 3,500,000 gallons.

The pumps are four in number, located at the bottom of a deep well at one side of the engine, and operated by a system of gearing. They are plain plunger-pumps, with a diameter of plunger of 22 inches and stroke of 4 feet. The average speed when in use is about 10 (double) strokes ordinarily, and from 12 to 18 per minute in case of fire. The force-main directly connected with these pumps is 16 inches diameter, and the head maintained is about 122 feet at the pump-house. The valves in the pump-cylinders are rubber-faced wood-seated puppet-valves, with a lift of about 2 inches, diameter unknown. These pumps were guaranteed to pump 4,500,000 gallons per 24 hours, but are not employed at more than 3½ million. No duty-trial of the engines has ever been made.

In the construction of the Hartford water-works the cost has been appropriated to the various departments as follows:

Expenditures.	Pumping-engine.	Engine-house, lot, inlet, pier, etc.	Storage-lot, reservoir lot and gate-house.	Distribution hydrants and gates.	Service-pipe.	New works at West Hartford and Farmington.	Total.
To March 1, 1857	$18,244 75	$50,047 95	$71,845 48	$182,010 75	$5,198 01	....	$330,947 70
In 1857	....	25 25	....	23,410 69	3,695 07	....	27,131 01
In 1858	....	78 60	....	3,646 68	2,545 92	....	6,271 20
In 1859	....	1,213 81	23 34	6,250 15	2,328 11	....	9,815 41
In 1860	....	355 79	....	5,292 21	2,847 93	....	8,495 93
In 1861	....	66 04	641 00	8,098 68	1,438 28	....	10,244 00
In 1862	....	....	....	8,228 76	2,224 15	....	10,452 91
In 1863	....	....	....	12,347 05	2,129 63	....	14,476 68
In 1864	....	....	....	5,937 30	3,127 38	....	9,064 68
In 1865	....	....	....	1,663 65	1,622 19	....	3,285 84
In 1866	....	....	....	34,158 82	2,149 07	$205,542 52	241,850 41
In 1867	....	....	....	13,221 82	2,093 44	72,928 91	88,244 17
In 1868	....	....	....	13,140 34	4,592 21	86,449 41	104,181 96
In 1869	....	....	....	13,222 87	3,597 46	27,461 42	44,281 75
In 1870	....	....	....	26,665 06	4,776 71	13,113 64	44,555 41
In 1871	....	....	8,000 00	30,528 68	4,852 14	200 00	43,580 82
In 1872	2,880 00	....	....	36,229 83	5,338 45	496 79	44,945 07
In 1873	9,600 21	....	1,115 50	53,770 22	4,810 61	9,825 50	79,122 13
In 1874	....	....	....	21,501 80	4,806 59	111,685 20	137,993 59
In 1875	....	....	....	16,706 05	3,898 54	57,371 80	77,976 39
In 1876	....	....	....	13,141 23	2,134 99	7,629 04	22,905 26
In 1877	....	....	....	7,761 34	1,372 77	862 10	9,996 21
In 1878	....	....	....	1,875 68	1,694 87	11,544 94	15,115 49
In 1879	....	....	....	2,718 36	1,629 33	84,124 86	88,472 55
Total	30,724 96	57,787 53	84,625 27	560,128 57	74,995 70	687,236 22	1,495,408 25

The main conduit from the West Hartford reservoir consists of 51,896 feet of 20-inch pipe, laid in two parallel lines, one being cement-lined wrought iron and the other cast iron.

The distribution is carried out by pipes of the same character as the conduit, of diameters 3, 4, 6, 8, 10, 12, 16, 20, and 24 inches, the different lengths of which are:

	Feet.
3-inch	2,255
4-inch	44,171
6-inch	216,487
8-inch	21,796
10-inch	4,463
12-inch	9,690
16-inch	18,782
20-inch	51,896
24-inch	140
Total	369,680

The total length of pipe laid is $70\frac{3080}{5280}$ miles, divided as follows: $54\frac{4687}{5280}$ miles of cast-iron and $15\frac{3723}{5280}$ miles of wrought-iron and cement pipe.

The consumption amounts to about 5,000,000 per 24 hours, and the number of water-takers is about 5,000.

The annual expense of maintenance and repairs for 1879 was as follows:

Interest on bonds	$62,120
Repairs	17,481
Current expenses	13,513
Total	93,114

The total number of gates in use is 575, and of hydrants 362, Holyoke patent post.

The purity of the water may be judged from the following analysis by Professor B. Silliman in 1861:

No. 1.—*From Connecticut river:*		
Solids	grains per imperial gallon	3.07
Organic matter	do	1.26
Inorganic matter	do	1.81
Carbonate of lime	do	0.01
Hardness	degrees	1.64
No. 2.—*From Trout brook:*		
Solids	grains per imperial gallon	3.91
Organic matter	do	1.95
Inorganic matter	do	1.95
Carbonate of lime	do	0.01$\frac{7}{10}$
Hardness	degrees	1.19

The works are at present under the charge of Mr. Edward J. Murphy, president and superintendent.

SPRINGFIELD, MASSACHUSETTS.

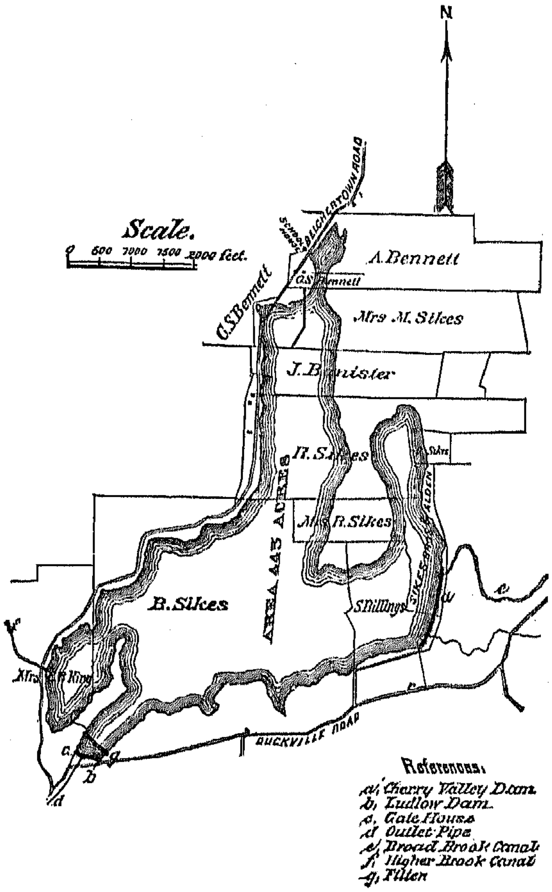
Springfield, containing a population of 33,340, is situated on the east bank of the Connecticut river, 26 miles north of Hartford, Connecticut. It is pre-eminently a city of manufactures. One portion of the city is in a low level area and the other on an elevated plateau. The plan of the streets is regular and rectangular.

The water-supply was first furnished to the city in 1840 by a private corporation, whose property was bought and enlarged in 1874 by the city. The system is by gravity from three artificial reservoirs, one located 10 miles east from the city and two within the city limits. The former, known as the "Ludlow reservoir", supplies the high-service mains, and the latter, known by the names of "Lombard" and "Van Horn", at a less elevation, supply the low service.

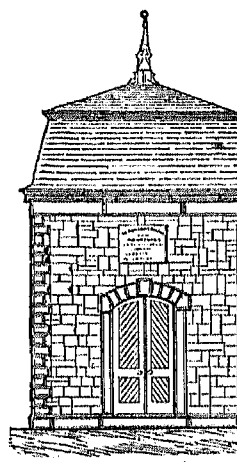
The former (Ludlow) reservoir was added to the system in 1874, and drains an area of about 3 square miles. The soil overflowed by the reservoir was chiefly sand and gravel, with a small area of marsh and 281 acres of woodland, the rest having been under cultivation. The maximum elevation or head of water above the main street is 312 feet. The average annual rainfall in Springfield for 25 years is 45.33 inches.

The area of the Ludlow Reservoir water-surface is 445 acres, and its shape is shown in the accompanying map. The marshy portions were sanded over to a depth of 18 inches, and the part included between the Ludlow dam and the filtering dam, an area of $3\frac{3}{4}$ acres, was covered with sand to a depth of 2 feet.

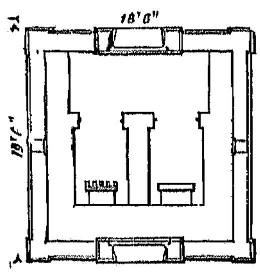
Two dams retain the waters of the different streams and form the reservoir. One of these is known as the Cherry Valley dam, and the other and smaller one as the Ludlow dam. The total capacity is 2,000,000,000 gallons. The latter is shown in section in the drawing on page 36. The whole front of the dam, from the gate or toe of the slope to the back of the priming-wall, was built upon a hard-pan foundation, and the base of the wall is sunk 3 feet into this foundation. This priming-wall is 18 inches thick, of stone in cement, and extends to within 2 feet of the top of the embankment, the top being covered with a rubble-wall 2 feet by 18 inches throughout the whole length of the dam. The dam is 2,352 feet long, 1,021 feet of it being only from 3 to 5 feet high, and of a total height of 39 feet. The length of the priming-wall is 1,297 feet. Height of top of bank above top of water, 4 feet. A roll-way or waste-weir, 34 feet long, paved with stone and resting upon a ledge, discharges the waste water. The width of embankment at the top is 25 feet, with a slope of 2 to 1 inside and out. The whole of the filling is puddled earth, and is faced with a granite riprap 12 or 24 inches thick. Through the base of the dam extends a waste-pipe 20



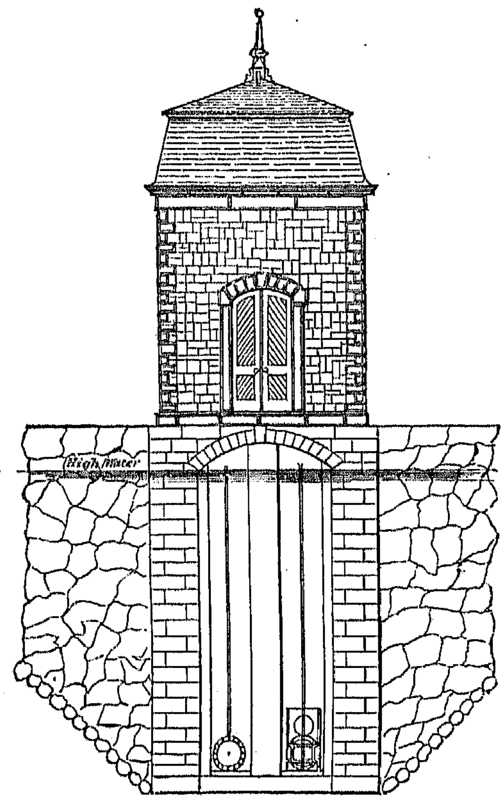
MAP OF THE CHERRY HILL RESERVOIR.



Front elevation.



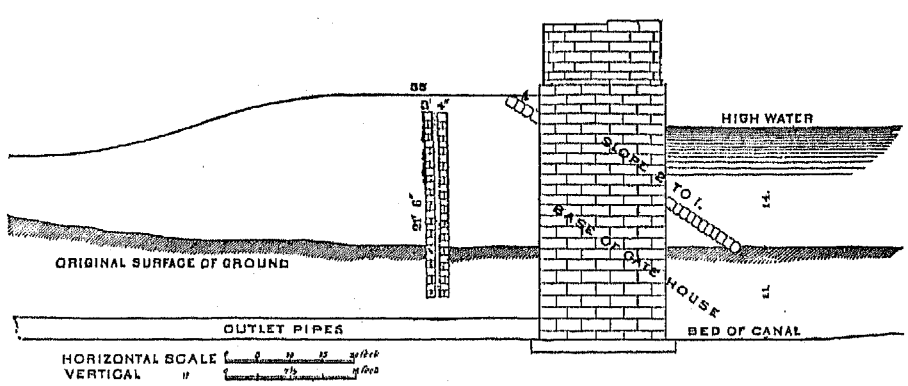
Ground plan.



Rear elevation.

inches in diameter, surrounded by stone masonry for its entire length and provided with a gate at each end, the upper one being inclined at the angle of the inner slope, and operated from the top of the dam by a rod. A dry-stone drain, filled with loose stone, and 5 feet square, extends along the whole lower toe of the dam.

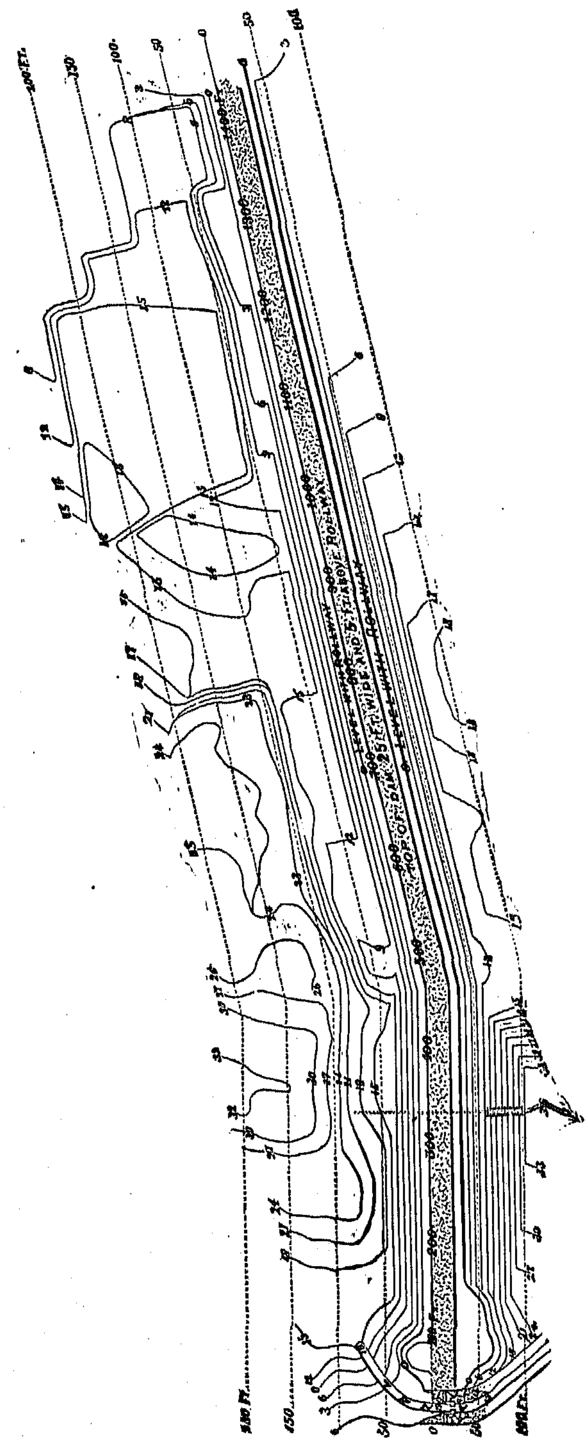
The Ludlow dam, the position of which is shown on the plan of the lake, is somewhat similar in construction to the Cherry Valley dam, being an earth puddle embankment with a masonry priming-wall of 3 feet 4 inches



SECTION THROUGH LUDLOW DAM.

thickness, which rests on a stratum of gravel and hard pan, and 18 inches below the foundations of the remainder of the dam. This wall, of rubble in cement, is built in two vertical courses, separated by a space 6 inches in width filled with concrete, the total height being 21 feet 6 inches, and rising to within 2 feet of the top of the embankment. The total length of the dam is 496 feet, the priming-wall being of the same height. Width of banks at top 35 feet; inner slope 2 to 1, outer 4 to 1; the former paved with stone as in the other dam. The top is 4 feet above high-water surface. The depth of water in front of this dam averages 14 feet. The cut shows the construction of this dam. Another cut shows the details of the gate-house, which contains two outlets—one 30 inches in diameter, running nearly through the dam, and one 24-inch supply-main. The former is for use when the consumption shall increase in the future. The whole gate-house measures 18 feet 6 inches by 19 feet 6 inches on the outside, and, as shown in plan, can be divided into three chambers by stop-planks sliding in grooves in the masonry. At present a set of sliding screen is placed in the compartment of the 24-inch main.

One end of this dam is 100 feet and the other 300 feet distant from the so-called filter-dam. This extends across the arm of the lake directly in front of the Ludlow dam, and is a dry rubble wall forming a retaining-wall for

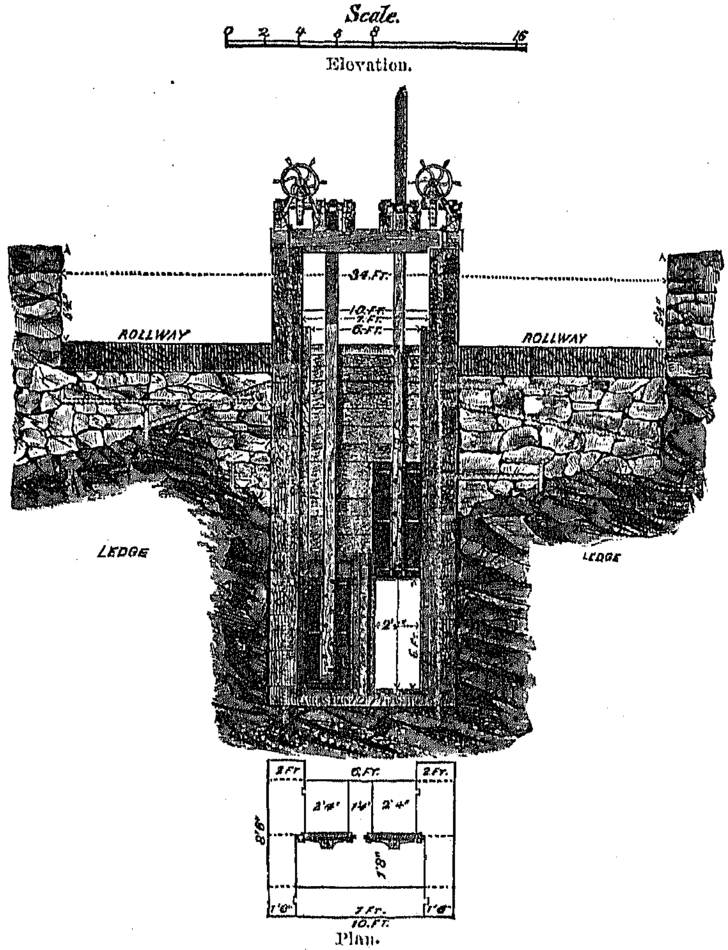


PLAN OF CHERRY VALLEY DAM.

a quantity of sand, and leaving an open space 100 feet long, in which filtering-screens may be placed on frame-work. Over this space a bridge is built. The space between the filter and the Ludlow dam is covered with a layer of clean sand.

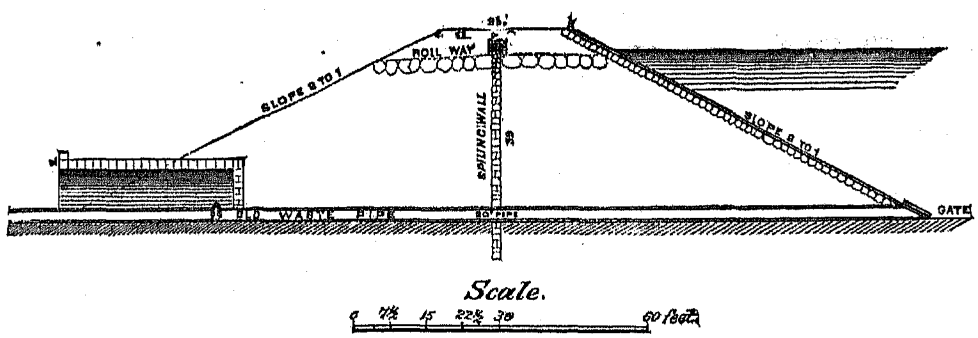
From this reservoir 56,410 feet of 24-inch main conveys the water into the city through 3,736 feet of cast iron, 52,506 feet of wrought iron cement-lined, and 168 feet of wrought-iron tube. The cement pipe is coated and bedded in cement. Owing to the defective character of the foundation of the Cherry Valley dam a large amount of leakage takes place beneath it, and it was found necessary to build a set of waste-gates in the roll-way or waste-weir as a sort of safety-valve. A plan and elevation are annexed. This permits the drawing off of the water very rapidly in case of any impending failure of the dam.

The position of the waste-weir is shown in the plan of the dam. The capacity of discharge of these safety-gates is estimated at 540 cubic feet per second to draw off the first foot of water below the top of the weir.



ROLL-WAY AND WASTE-GATES, CHERRY VALLEY DAM.

The area of the Van Horn reservoir at high-water level is 10 acres, with a capacity of about 100,000,000 gallons. It is irregular in outline, with an earth dam about 1,000 feet long, having a clay-puddle priming-wall 12 feet thick at base and 4 feet at top. The total width of the bank at the top is 15 feet, with slope of 2 to 1, and a total height of 30 feet. The reservoir was built in 1867 by the water company at a cost of $10,000. One 20-inch and



one 12-inch pipe convey the water from the gate-chambers. This was followed by the construction of the smaller Lombard reservoir, which is identical in construction with it, the dam being 250 feet long and 30 feet high, with a capacity of 10,000,000 gallons and an area of 3 acres. There are two effluent pipes, as before. It was finished in 1868 at acost of $2,000. The two dams of the Ludlow reservoir are said to have cost $113,400. The drainage area of the Van Horn and Lombard together has been estimated at about 4,299 acres.

The elevation of the Van Horn reservoir at water-level is 198 feet above city datum, and the depth 30 feet. Of the Lombard the high-water surface is also 198 feet above datum, and depth 22 feet.

The distribution system contains 55 miles of cast-iron and cement-lined wrought-iron pipes, divided about as follows: $1\frac{1}{4}$-inch, 211.0; 2-inch, 8,782.0; 3-inch, 58,564.0; 4-inch, 41,926.0; 6-inch, 63,372.5; 8-inch, 54,726.0; 10-inch, 8,905.0; 12-inch, 20,283.0; 16-inch, 22,180.1; 20-inch, 4,364.5; 24-inch, 56,524.5; total, 339,838.6 linear feet.

The sizes in use may be seen from the table. There are 378 Matthews' patent fire-hydrants in use. This system supplies about 3,500 water-takers, representing about that number of service-pipes.

The consumption averages about 3,000,000 gallons per day, but the quantity is not exactly known. The first cost of the works is given at $1,250,000, and the annual expense of maintenance and repairs for 1879 was $10,369. The analyses of water in the Ludlow reservoir, given below, are by Professor W. R. Nichols, of the Massachusetts Institute of Technology, at Boston:

Examination of water from Ludlow reservoir.

Locality.	Date.	Parts per 100,000.							Grains per United States gallon.					
		Ammonia.	"Albuminoid ammonia."	Solid residue. Inorganic.	Solid residue. Organic and volatile.	Solid residue. Total at 212° F.	Chlorine.	Oxygen required to oxidize organic matter.	Ammonia.	"Albuminoid ammonia."	Solid residue. Inorganic.	Solid residue. Organic and volatile.	Solid residue. Total at 212° F.	Chlorine.
Reservoir near entrance of Broad brook	December 25, 1875	0.0084	0.0172	3.60	2.16	5.76	0.20	0.82	0.0049	0.0100	2.10	1.26	3.36	0.12
Center of reservoir 6 feet below surface	December 25, 1875	0.0162	0.0314	3.52	2.88	6.40	0.21	1.31	0.0094	0.0183	2.05	1.68	3.73	0.12
Between gate-house and filter 6 feet below surface.	December 25, 1875	0.010[illegible]	0.0320	3.36	2.92	6.28	0.22	1.45	0.0004	0.0187	1.96	1.70	3.66	0.13
Broad brook near reservoir	January 17, 1876	0.0066	0.0128	3.14	1.88	5.02	0.20	0.89	0.0038	0.0075	1.83	1.10	2.93	0.12
Reservoir	January 17, 1876	0.0126	0.0316	2.64	2.44	5.08	0.20	1.33	0.0073	0.0184	1.54	1.42	2.96	0.12
Reservoir, second sample	January 17, 1876	0.0152	0.0318	2.40	2.64	5.04	0.20	1.40	0.0089	0.0185	1.40	1.54	2.94	0.12
Between filter and gate-house	January 17, 1876	0.0120	0.0340	2.46	2.98	5.44	0.20	1.29	0.0070	0.0198	1.43	1.74	3.17	0.12

The works are controlled by Messrs. N. W. Talcott, S. W. Porter, and C. O. Chapin, water commissioners.

The experience of this city with cement-lined pipes is thus tersely given by Mr. G. A. Ellis, the city engineer: "Our experience is probably as favorable as any in the country, but not enough so but that its use for new work for the last five years has been discontinued."

NEW LONDON, CONNECTICUT.

New London contains a population of 10,537 inhabitants, and is located upon the eastern bank of the Thames river near its mouth. Topographically, it is located on ground rising from the river and more or less hilly. The principal streets are pretty regularly laid out at right angles to each other, with a few diagonal or irregular streets intersecting.

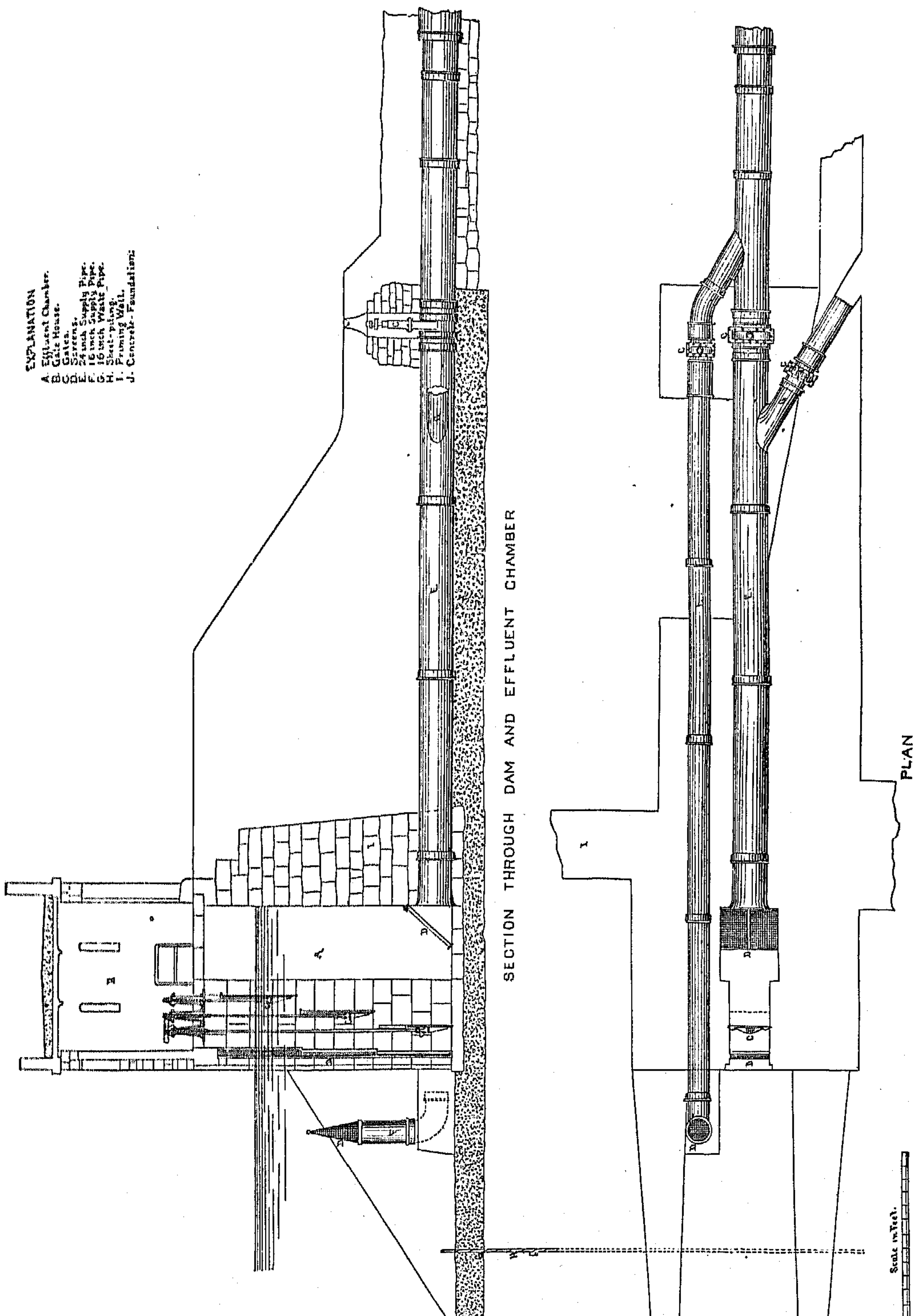
Water was first introduced into the city in 1872 by the city authorities, and is derived by gravity from an artificial reservoir known as lake Konomoc, situated about 6 miles out of the city. The water-shed of the lake is calculated at about 1,296 acres, while the area of the water-surface in the lake is 225 acres. The storage capacity is estimated at 600,000,000 gallons. The bottom was cleared of muck, stumps, etc., and the soil remaining was principally clean and sandy. The depth of water is about 13 feet at high water.

The dam is located at a point on Lake Konomoc brook where the banks are within 225 feet of each other, and are composed of layers of sand and gravel. At this point a substratum of quicksand, from 4 to 6 feet thick, is overlaid by a layer of about 2 feet of hard pan, upon which again are a few feet of light soil. Upon the hard pan the priming-wall of rubble masonry was built after a layer of 2 feet of concrete had been formed about $10\frac{1}{2}$ feet in width and carefully united with the hard pan. The priming-wall at its base, where it thus rests on the concrete, is $4\frac{1}{2}$ feet thick, and diminishes to a thickness of 2 feet at a height of 1 foot above high water. The total length is about 275 feet, which includes the distance to which it extends into the banks at the ends, amounting to about 50 feet.

The face of the dam is puddled, lined with stone riprap from 8 to 12 inches thick, and sloped $1\frac{1}{2}$ to 1 up to a point 1 foot below high water. The riprap facing is capped with a vertical wall 5 feet high and from 2 to 4 feet thick. The back of the dam is gravel-banked to a slope of $1\frac{1}{2}$ to 1, and giving the total width at the top of 25 feet, the priming-wall being in the center. The overfall, as detailed by Mr. W. H. Richards in his report of 1873, is situated in the center of the dam, is 9 feet thick at the bottom and 4 feet at the top, surmounted by caps of dressed masonry 2 and $2\frac{1}{2}$ feet wide, respectively. The 2-foot caps are 6 inches above the edge of the overfall, and at this point the latter is 15 feet wide; above the 2-foot caps the width of the overfall between the wing-walls is 25 feet. The wing-walls flank the overfall, and are 7 feet 6 inches wide at base, terminating 3 feet wide at the level of the top of the dam.

A chestnut apron laid in concrete and extending 12 feet in front of it, together with a 2-inch sheet-piling, protects the dam from being washed away in front of the overfall. A paving of the space between the wing-walls extends also 45 feet from the apron.

The effluent chamber east of the overfall is 4 feet by 4 feet 6 inches inside, with a screen opening 30 inches wide, having three cast-iron gates at different depths, each 24 by 30 inches. The screens are copper wire with $\frac{1}{8}$-inch



mesh. The gate-house above the effluent chamber is of masonry, and 8 by 10 feet by 9 feet high, containing the hoisting machinery. From the effluent chamber a 24-inch cast-iron pipe runs through the dam and connects with the main conduit.

On account of the substratum of quicksand, it was deemed advisable to drive a row of sheet-piles 8 or 10 feet into the quicksand 20 feet in front of the priming-wall and through the hard pan. The piles were tongued and grooved and 2 inches thick, and fastened together by bands of 6-inch pine timber.

About 1 mile above the dam a filter dam 20 feet wide by 12 feet high, of loose gravel, is built and used as a driveway.

The main conduit is of Scotch-clay pipe, such as is employed in sewer construction, and 24 inches in diameter, laid in 3-foot lengths with cement joints.

A stand-pipe situated 6,826 feet from the dam consists of a 20-foot vertical wrought-iron pipe 20 inches in diameter, with its top about 2 feet above the level of the lake. It is intended to lessen the shock on the conduit caused by a sudden closing of a gate. The total length of clay pipe is 6,826 feet, and at the point where the stand-pipe is located the foot of the latter is 18½ feet below the overfall. At this point the "main" begins. It is a cement-lined wrought-iron pipe buried in cement, and 16 inches in diameter, extending into the central portion of the city, a total distance of 27,290 feet.

The head of water in the city varies from a maximum of 180 feet to an average of 125 feet. No distributing reservoir is used.

The distribution mains are of the same material as the 16-inch main, 4, 6, 8, 10, and 12 inches, respectively, in diameter, with a total length of 15 miles. There are 100 hydrants, made by the Boston Machine Company, and 80 gates.

The consumption has never been estimated, but may be approximated at 2,000,000 gallons per day. The number of consumers or service-pipes is 1,250. The rainfall in New London varies from 60 inches, as in 1874, to 40 inches, as in 1878, averaging about 48 inches per annum.

A statement of the total cost of the works to September 1, 1880, is appended:

Pipes and appendages	$200,794 30
Land and damages	22,365 89
Lake Konomoc and dam	37,974 45
Service-pipes and temporary mains	22,091 70
Fencing	4,850 72
Extension No. 3	467 06
Extension No. 4	918 30
Meter account	1,196 18
Hydrant account	54 77
Street commissioners	326 70
Manufacture of service-pipes	600 00
Cash	366 37
Total	292,206 44

The first cost was $264,000. The annual expense of maintenance and repairs is about $3,000, not including interest.

The following is an analysis of the water (results expressed in parts in 100,000):

Locality.	Date.	Ammonia.	"Albuminoid ammonia."	Solid residuum. Inorganic.	Solid residuum. Organic and volatile.	Solid residuum. Total at 212°F.	Authority.
Lake Konomoc near bottom, at a depth of 25 feet.	Dec. 23, 1879	0.005	0.016	1.60	1.20	2.80	W. R. Nichols.
Lake Konomoc at outlet	Dec. 23, 1879	.....	.....	.....	.....	3.00	W. R. Nichols.
New London, water commissioner's office	Dec. 11, 1879	0.006	0.008	.....	.....	3.88	W. R. Nichols.

PORTLAND, MAINE.

Portland has a population of 33,810. It is situated on a piece of land projecting from the west shore of Casco bay, 3 miles long by ¾ of a mile wide, rising rapidly at both ends. It is regular in plan of streets, and is chiefly a commercial center for the state.

In 1869 the Portland Water Company introduced a gravity supply for domestic and fire purposes from lake Sebago, lying 17 miles west of the city. It has a drainage area of 100 square miles. A cement masonry dam, constructed at its outlet, raises the water to a higher level than the natural surface of the lake. This dam is 148 feet long and 15 feet high, with a thickness of 13½ feet at bottom and 6½ feet at top, a perpendicular back and a sloping face of 7 horizontal to 15 vertical. Its cost is approximated at $40,000. There is no gate-house connected in the dam with the main conduit, but the latter comes from a different part of the lake by a conduit of wood 4 feet square, extending 80 feet out into the lake. At a brick gate-house, 27 by 33 feet, on the bank, this wooden conduit enters a brick conduit 2½ by 3½ feet and 2,000 feet long, when it enters a tunnel 3½ feet high, 6 feet wide, and 1,360 feet long, with a fall of 1.775 feet. Another length of 2,080 feet brick conduit with semicircular crown and curved invert connects at another gate-house, 15 feet square, with two cement-lined wrought-iron pipes, one 20 inches in diameter and 83,119 feet long, the other 26 inches in diameter and 18,500 feet long, whence it is diminished to 24 inches in diameter and extends to the city side by side with the 20-inch pipe, a distance of 63,669 feet, making *two main conduits entering the distributing reservoir. The high-water surface in the lake is 267 feet above mean* tide in the bay.

The distributing reservoir is nearly square in plan, with earth embankments, puddle-faced to a depth of 18 inches, and is protected by a stone riprap 8 inches thick. Thickness at top of banks, 20 feet; depth when full, 28 feet; capacity, 12,000,000 gallons; area of high-water surface, 62,463 square feet; area of bottom, 32,100 square feet; average length of each side at water-line, 250 feet. The surface is 160 feet above tide-water. The banks slope $1\frac{1}{2}$ to 1 inside and out.

The water-supply is abundant, except in unusual seasons when the level of the lake has been seriously lowered by prolonged drought.

From the distributing reservoir the water is supplied to the consumers through cement-lined pipes 16, 12, 10, 8, 6, 4, 3, and 2 inches, respectively, in diameter, of a total length of 65 miles, at the estimated rate of 4,500,000 gallons per day. The number of consumers or water-takers in 1880 was 4,414.

Both the Johnson and Lowry fire-hydrants are in use, to the number of 202 in all.

The original cost of the works is unknown, but they have cost, up to January, 1880, the sum of $2,251,000, the running expenses being $10,000 per annum.

The water is of remarkable transparency, and contains 6.8 parts per 100,000, or 1.5 grains per gallon of inorganic matter. The works are at present controlled by D. W. Clarke, president, and George P. Westcott, superintendent and secretary.

NORWICH, CONNECTICUT.

Norwich contains a population of 15,112 inhabitants. It is situated upon the Thames river near the mouth of the Yantic, and in a valley surrounded on all sides by high hills. Portions of the town are much more elevated than others, and the streets are more or less irregular. The business interests are chiefly manufacturing.

The water-works are under the control of the city, and water was introduced in 1869. It is a gravity system, deriving its supply from a number of small brooks and springs located about $2\frac{1}{2}$ miles out of the city. The engineer of the work was James T. Fanning, C. E., and the following details are obtained from his "Memoranda":

The water-shed lies along the summit of a section of the range of high land between Scotland road and Canterbury turnpike, and the site of the reservoir is in the valley on the western slope of this range, which leads its waters to the Yantic river. On the western slope of this range, and opposite the site of the reservoir, lies another valley running eastward to the Shetucket river. These two streams at one point approach each other within 500 feet. About 1 mile below this the dam is located. A dam 30 feet high gives an overflow into the eastern from the western valley.

The water-shed is calculated to be about 483 acres, according to the surveys, with a rainfall of 55.89 inches as an average of seven years. The capacity of the reservoir to the level of the overflow is 350,000,000 gallons; its length, $1\frac{1}{4}$ mile; average width, 480 feet; depth, $16\frac{1}{2}$ feet; and area, 66 acres.

The dam is an earthwork embankment 25 feet wide on top, interior slope about 2 to 1, but convex near the base, as shown in the accompanying cut; exterior slope, $1\frac{1}{2}$ to 1. A priming-wall is built through the center of this, 5 feet thick at base and 2 feet at the top, of stone laid in cement, and founded upon a ledge of rock. The total height of the dam is 35 feet, and length 468 feet on the top. The head of water in the town varies from 135 to 250 feet, the latter at tide-water in the Thames river. The dam is faced with 18 inches of stone riprap.

The well-house construction may be seen from the drawing, and consists of a "circular masonry tower built up through the interior of the slope to above the water-line". Diameter on inside, 8 feet.

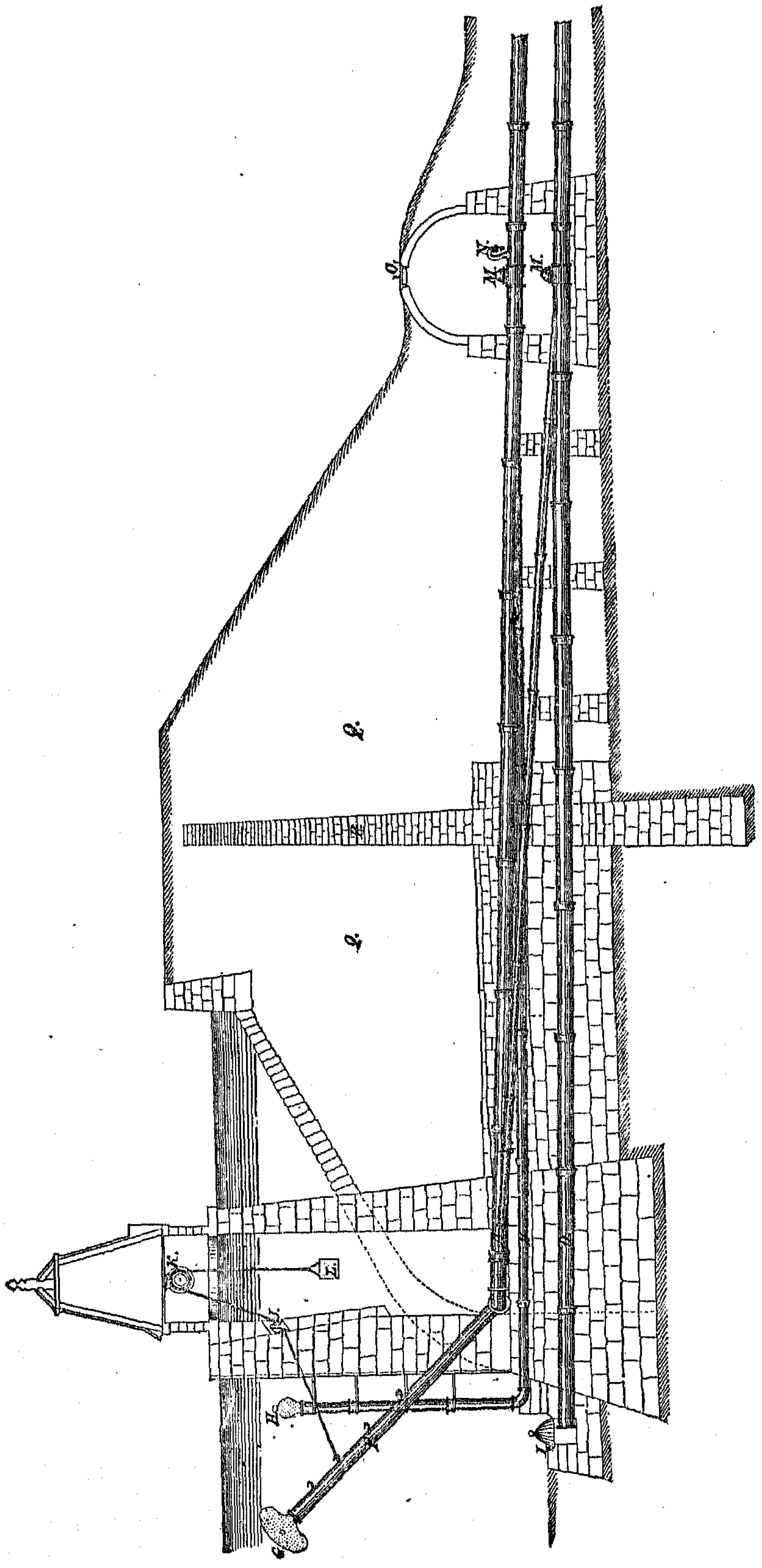
A 16-inch cast-iron waste-pipe, D, from the toe of the slope at the well-house passes through the dam, supported on masonry piers. An 8-inch branch-waste, C, serving to empty the well-house, runs side by side with the former, joining it outside of the dam. A 16-inch supply-pipe, with adjustable inlet, and a 10-inch branch supply-pipe, A and B, also pass through the dam side by side like the wastes.

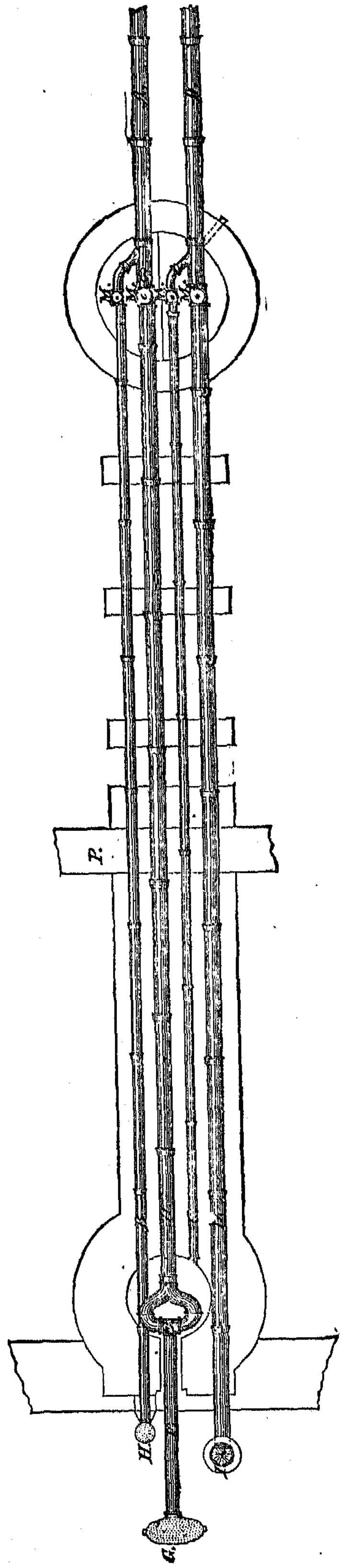
The adjustable inlet pipe is unique, and deserves mention in the words of its engineer:

A Y-shaped pipe-casting, forming the base of the effluent pipe, rests on the floor of the well-house, and is connected with the main *supply-pipe already mentioned.* The arms of the Y are curved into heart-shape toward each other, are flanged at their ends, and 14 inches diameter. The foot of the adjustable pipe is in ⊥-form and connected with the heart-arms by flexible joints allowing free motion in a vertical plane. Length of adjustable or movable arm 27 feet, and its end can be raised above the surface of the water.

This inlet-pipe is of copper, and a screen covers the open end. A block and tackle in the well-house supports a counterbalancing weight.

The gate-house is a circular stone construction of 11 feet inside diameter and the top even with the surface at the toe of the exterior slope. A masonry culvert receives the discharges of the waste-pipes heretofore described, and empties into the brook below the dam. A rubble-masonry wall is built 3 feet high entirely around the basin, with appropriate passage-way and surface-wash culverts. About 20,000 stumps were cleared from the bed of the reservoir during the construction. The level at high water in the reservoir is 4 feet below the top of the dam. The reservoir





has been stocked with fish, and serves both as impounding storage and for distributing. The water is brought from the reservoir to the city through a cement-lined wrought-iron pipe buried in cement and 14 inches in diameter, of 9,000 feet length, and one 16-inch cast-iron main 9,000 feet long. The distribution is accomplished by about 31 miles of cement-lined pipes with some considerable lengths of cast iron. The sizes used are 10-, 8-, 6-, 5-, and 4-inch.

The number of water-takers averages about 3,000, and the consumption is estimated at from 750,000 to 1,000,000 gallons per day.

Two hundred and forty-seven gates and 254 hydrants are in use at the present time, the latter being made by the Boston Machine Company.

The original cost of the works was about $272,000, including about 9 miles of distribution mains, one 14-inch main, and 68 hydrants. The total cost to January 1, 1880, is about $411,879, and the annual expense of maintenance and repairs, not including interest, is about $4,000.

The city is about to construct additional works to supplement the present insufficient supply.

The quality of the water may be seen from the appended analysis by Professor Silliman, made in 1873, to be of exceptional purity and softness.

The present engineer and superintendent is Mr. H. B. Winship, of Norwich, Connecticut.

Analysis of the water.

[Results expressed in grains per gallon.]

Sample No.	Source.	Mineral matter.	Organic and volatile.	Total solid.	Degrees of hardness.
1.......	22 feet below lake surface....	1.166	0.70	1.860	0.500
2.......	12 feet below lake surface....	1.140	0.60	1.740	0.540
3.......	Surface of lake...............	1.050	0.58	1.630	0.510
4.......	Waste-pipe of lake...........	1.300	0.70	2.000	0.560
5.......	House faucet.................	1.071	0.70	1.806	0.500
	Average	1.167	$0.67\frac{6}{10}$	1.844	0.546

CONCORD, NEW HAMPSHIRE.

Concord, with a population of 13,843 inhabitants, is located on the right bank of the Merrimack river. It stands on level ground, gradually rising from the river-bank upon a granite formation. Its industries are manufacturing, the products being agricultural implements, belting, wagons, and cotton and woolen goods.

In 1873 the municipal authorities introduced water into the city from Pennacook lake, formerly known as Long pond, 300 acres in extent, and situated about 2.84 miles in a northwesterly direction from the center of the city. The drainage area of this pond is 3 square miles, and the elevation of high-water surface is 122 feet above Main street opposite the state-house. A dam has been built across the outlet of the lake, about 2,000 feet below an old dam, adding 200 acres of water-shed. The soil is sandy and is underlaid by granite.

The dam is an earth embankment, 110 feet long at bottom by 280 feet at top, 100 feet wide at bottom and 20 feet at top. Total height 20 feet, with a slope of 2 to 1 outside and in. Through the center of this dam, extending the whole length, is a masonry priming-wall of granite in cement, 3½ feet thick at base and 2 feet thick at top. The face of the dam is protected by a riprap wall of quarried granite in cement.

The top is used as a driveway, connecting the opposite sides of the creek. A masonry gate-house rises through the upstream side of the dam, 13 feet square at the base, tapering to 10 feet square at the top, a height of 23.5 feet of masonry, and connects by a bridge with the top of the dam. From this three cast-iron pipes, two of which are 18 inches and one 24 inches in diameter, extend through the dam. One of the former connects with the main to the city for the present supply, and the other is for use at a future period, when an additional line of conduit shall connect with the city. The 24-inch pipe supplies the power to mills located below the dam, and the flow through it is regulated by a gate operated within a small gate-house 8 feet square, of brick, on the lower side of the dam. About 300 feet north of the main dam an overflow 40 feet wide has been built, the top being 4 feet below the crest of the dam, the elevation of which is 185 feet above low-water mark on the Merrimack.

A brick conduit has been built, connecting the outlet below the lower dam with the water of the upper pond. This conduit is 2,000 feet long and 26 by 30 inches in diameter. Both ends are closed by gates.

As the water has to be measured, three Gem meters are placed in the iron supply-mains 200 feet below the dam. This is the only instance in the country where the whole supply is measured, and is due to the limited amount allowed by the mill-owners using the power of the stream and originally owning the rights. These meters are inclosed in a stone chamber 10 by 16 by 8 feet, and covered with earth. They are fitted into the two 16-inch iron mains from the reservoir, which combine on leaving the meters into one 14-inch main of cement-lined wrought iron, 3½ miles in length to the city. The distribution mains are 4, 6, 8, 10, and 12 inches, respectively, in diameter, all of cement-lined wrought iron, with a total length of 23 miles. Ninety-six Matthews patent fire-hydrants are in use. The daily consumption averages 575,000 gallons to 2,000 water-takers.

The cost of the dam was $19,523, and the appended list of items will show the total cost up to April, 1875, the date of the completion of the works:

Summary of all expenditures to December 31, 1873.

Conduit and works at Long pond	$20,360 53	Engineering and superintendence	$6,955 87
Main pipe	44,411 15	Incidentals	2,396 37
Distribution pipe	99,471 59	General construction	895 26
Gates and hydrants	18,106 18	Damages	61,687 60
Service-pipe	11,401 24		
Dam, gate-house, and appendages	19,523 99	Total	285,777 70
Shop and tools	567 92		

Disbursements, January, 1874, *to April*, 1875.

Maintenance and care of works	$1,808 52	Interest on the same	$1,457 80
Extensions of distributing pipes, 6-inch and 4-inch	2,554 60	Buildings and water-privilege of Farnum & Humphrey	5,000 00
Extensions of distributing pipes, 1-inch and $\frac{3}{4}$-inch	2,900 60	Cooledge land and water rights	5,500 00
		Meters	283 30
Service-pipes	4,839 18	General construction	1,249 27
Long Pond works	2,292 58	Pipe purchased and on hand	324 60
Flowage on the shores of Long pond	900 00		
Amount paid Torrent Aqueduct Company and Nathaniel White	20,000 00	Total	49,110 45

The pipe of the whole system is distributed as in the appended table:

	Feet.		Feet.
30-inch main	1,950	6-inch distribution	37,911
16-inch main	151	4-inch distribution	45,240
14-inch main	13,556	1-inch distribution	11,747
14-inch distribution	3,704	$\frac{3}{4}$-inch distribution	9,830
12-inch distribution	1,622		
10-inch distribution	3,034	Total	137,412
8-inch distribution	8,667		

The total cost of the works to date has been somewhat over $350,000, with an annual cost for the year 1879 of $2,468. The water, coming largely from a granitic region, compares favorably with that in other cities in purity. The analysis of the water from Long pond, made by S. Dana Hayes, state assayer of Massachusetts, in 1872, shows the following results:

	Grs. per gal.
Inorganic matter	0.32
Organic matter	1.48
Total impurities	1.80

RUTLAND, VERMONT.

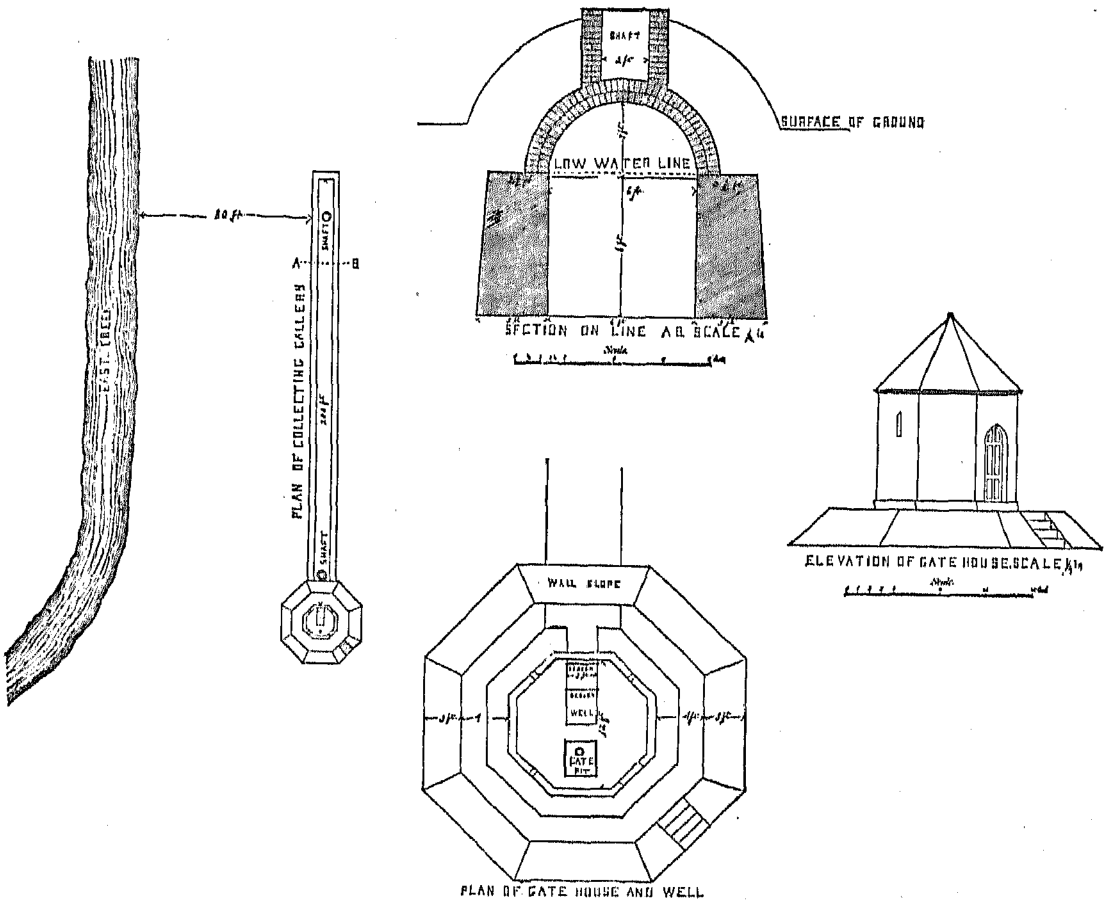
This city, situated near the center of the state, contains a population of 7,502 inhabitants. The city is situated in a narrow basin surrounded by considerable hills, and its streets are of steep grade in very many cases, with but little regularity in plan. The strata underlying the city proper are generally Æolian limestone of considerable thickness, with substrata of quartz-rock. A narrow outcrop of Pliocene (Tertiary) makes its appearance a short distance to the east, separating the limestone from the quartz, but does probably not extend beneath the city.

Water for domestic purposes was first introduced into the city in 1853 by the city authorities. It is supplied by two small streams, known as East creek and Tanyard brook, rising in a spur of the Green mountains, about 3 miles east of the city. The North brook falls rapidly in its course, in some cases as much as from 10 to 40 feet in short distances, making the formation of any considerable sheet of water by damming an impossibility. A reservoir, however, has been built in the bed of the stream, and a main carries the water to the distributing reservoir in town, about 1 mile from its center. This piping consists of 350 feet of 6-inch cast-iron pipe, followed by a length of 350 feet of 5-inch pipe, and the remaining distance, equal to 10,025 feet, is 6-inch cast iron, a total of 2.03 miles. From a similar construction on East creek a length of $3\frac{1}{8}$ miles of 12-inch iron pipe brings the water to the reservoir in town as before. The connection with the reservoir is so arranged that the water can be sent to the town through the reservoir or around it, or from both reservoir and conduit. The drainage area of these streams has never been accurately ascertained by survey. The annual rainfall upon their water-sheds has been averaged from observations of ten years' duration at $36\frac{1}{2}$ inches, of which perhaps 65 per cent. is collected in the drainage-basins, owing to the abruptness of their slopes.

The dam on Tanyard brook is constructed of cement masonry, and is but 15 feet long by 8 feet thick at base and 4 feet at top. It contains no gate-house, the outlet-pipe having a plug fitted into it on the upstream side of the dam. The supply from East creek was introduced in 1876, and the collecting gallery built as shown. The

North Brook water-shed has been estimated at 900 acres, yielding an average daily supply of 1,400,000 gallons. The actual consumption, as estimated, is 1,250,000 gallons per day, supplied to about 900 takers.

The distributing reservoir is an earthwork trapezoidal in plan, 65 by 67½ by 35 by 58 feet, and 15 feet deep. A central puddle-wall, running through the embankments, is 4 feet thick. The slope of the faces inside and out is 1½ to 1, the former being faced with riprap 6 inches thick. The capacity is calculated at 1,250,000 gallons. The maximum head from this to the lowest part of the city is 156 feet. The distribution is carried out through cast-iron pipes, 3, 4, 5, 6, 8, and 12 inches in diameter, with a few as small as 2 inches in diameter. Total length, $2\frac{3328}{5280}$ miles.



RUTLAND WATER-WORKS.

The records of the cost having been burned in a recent fire, it is only approximated at $28,500, with an annual expense for maintenance and repairs of $2,000 (in 1879). Fifty Matthews' patent fire-hydrants are used.

Rutland presents one of the most economical systems in the country for a city of its size, so far as the original cost is considered. The water, which is roiled during freshets, is of good quality at other seasons, as the following analysis by Professor Nichols will show. The sample was taken from an ordinary tap on the service-mains in town. Results are expressed in grains to a United States gallon:

Ammonia	0.0026
"Albuminoid ammonia"	0.0048
Inorganic matter	2.0
Solid residue—organic and volatile	0.3
Total at 212° Fahrenheit	2.3
Chlorine	0.06
Hardness	1.2°

The works are at present under the superintendence of Mr. J. M. Davis.

The accompanying cut shows the construction of a gallery built about 80 feet distant from the banks of East creek, and collecting the water thence by infiltration through the sandy and gravelly soil intervening.

2.—DIRECT PUMPING.

INDIANAPOLIS, INDIANA.

Indianapolis, with 75,056 inhabitants, is situated on a perfectly level plain on the West fork of White river, in the center of the state of Indiana. Its interests are both commercial and manufacturing. The site of the city is composed largely of gravel and sand, and the streets are exceedingly regular in plan. In 1871 the water from White river was introduced by a private corporation.

Two wells were sunk on the banks of the stream 80 feet apart, and the bottom levels were joined together by a brick tunnel 5 feet in diameter laid with open seams without cement. These wells are 20 feet in diameter at the mouth, and one of these has a smaller one (12 inches diameter) sunk within it to a depth of 6 feet below. The wells are also built with dry brick. The first one built had an iron shell sunk 7 feet below the brick-work and on the inside, but not being strong enough was lined with brick. The water is derived in all probability by infiltration from the river. In 1879 a crib-work of timber filled with stone, 50 by 25 feet by 4 feet high, was sunk in the river, and the water was taken from it through a small square box in one end, whence it was led into the pumps, the wells having furnished an insufficient supply. Considerable trouble has been experienced from the clogging of the inlet-pipe, and also from the impurity of the water in the river. The works are located considerably within the upper line of the city limits. The system is direct pumping with Holly machinery. The old pumps, erected in 1871, consist of a gang of six single-acting piston-pumps 16 inches in diameter with 16-inch stroke, operated above by gearing from a set of turbines or a 2-cylindered Holly steam-engine, at pleasure.

In addition to these there is a set of three No. 14 Holly rotary-pumps run at 50 to 150 revolutions per minute, with an interior diameter $19\frac{3}{4}$ by $12\frac{1}{2}$ inches deep, with 10-inch inlets and outlets. Three turbines are in use, deriving their power from the central canal seen in the cut; the canal is owned by the works. These turbines are Dayton or American wheels 42 inches in diameter, and operated under a head of 16 feet at 60 or 80 revolutions per minute, according to whether the rotary or gang pumps are used. The steam-engine, for use when the water operating the turbines is for any reason unavailable, has two inclined steam-cylinders 16 inches in diameter with 27-inch stroke, operating a fly-wheel supported above them. It is run when in use at a speed of from 75 to 150 revolutions per minute.

The gang and rotary pumps are soon to be discarded as nearly worn out. In the former there is a single discharge-pipe to each pump, which contains two hinge-valves $3\frac{3}{8}$ by $11\frac{1}{2}$ inches.

The large Holly pumping-engine, built in 1875, is of the inventor's latest pattern. There are four inclined pumps, the rods of which are connected with the piston-rods of the steam-cylinders above them by a key readily detachable. The pumps are 15 inches in diameter with 33-inch stroke; four steam-cylinders 25 inches in diameter, with 33-inch stroke, operated non-condensing or compound condensing. The engine is operated for about one-third of the year. There are twelve suction and twelve discharge valves in each pump-cylinder, 6 inches in diameter by $\frac{3}{16}$-inch lift. The capacity of the pumping-engine is claimed to be 12,000,000 gallons per day, and a test trial is said to have given with best Pittsburgh coal a duty of 86,500,000 foot-pounds. The capacity of the gang pumps is about 3,000,000 gallons per 24 hours, and of the rotary about 2,000,000. They are usually in operation continuously, while the large Holly engine is idle about two-thirds of the year. The condenser of the latter is of the jet pattern, 4 feet 5 inches in diameter by 29 inches deep, with two air-pumps each 22 inches in diameter with 22-inch stroke.

Steam is supplied to the pumping-engines by three batteries of two boilers each. One battery consists of two Holly upright boilers each 7 feet in diameter by 10 feet high, multitubular, with 2-inch tubes, and an evaporation of $11\frac{1}{2}$ pounds of water per pound of coal from Indiana. The pressure in them averages 60 pounds.

In another battery of two boilers the boilers are horizontal 2-flue, 42 inches in diameter by 24 feet length of shell, the flues being 15 inches in diameter. The other battery contains two five-flue boilers 24 feet long and 60 inches in diameter. One of the flues is 15 inches, two 14 inches, and two 12 inches in diameter. The evaporation is 9.8 pounds of water per pound of coal.

The cost of the gang and rotary pumps, with connecting parts and two upright boilers, was $70,000, while the cost of the new engine without boilers was $45,000.

The water on leaving the pumps is forced directly into the distributing mains, the 24-inch main from the engine being tapped but a few hundred feet from the engine-house.

The distribution system comprises (1880) about 45 miles of cast-iron mains 24, 20, 18, 16, 12, 10, 8, 6, and 4 inches, respectively, in diameter. The average domestic pressure in them varies from 45 to 50 pounds. In case of fire it can be increased rapidly to about 120 pounds.

The number of water-takers being about 1,400, the consumption averages 4,000,000 gallons per day.

There are 600 Holly hydrants on the distribution system, on which the city has to pay $50 each per year.

Meters have been in use in considerable numbers, but for some reason the character of the water was such as to corrode them very rapidly and soon render them useless. As a consequence most of them were abandoned.

The first cost of the works was about $400,000, which has been increased by extensions, etc., to about $1,000,000. The annual cost of repairs and maintenance has averaged $25,000, but for 1880 is given at $65,000, exclusive of interest. The doubtful quality of water supplied has given rise to much complaint, but no correct analysis seems yet to have been made.

The works have recently changed hands, and a new company has organized, with Sidney M. Dyer as president and superintendent.

COLUMBUS, OHIO.

Columbus contains a population of 51,647 inhabitants, and is situated on the Scioto river 90 miles above its mouth. Its streets are laid out with perfect regularity. The site of the city is exceedingly level, resting on a formation chiefly of sand and gravel underlaid with blue clay. Its industries are manufacturing to a small extent, and commerce in grain, wool, and live stock. It may be called principally a residence city.

The water-supply was introduced in 1871, under municipal auspices, and is derived by pumping from an infiltration gallery on the north bank of the Scioto river, and is transmitted to the city by direct pumping with a set of Holly pumps.

The pumping station is located on the northerly bank of a stream known as the Olentangy river, near its confluence with the Scioto, and about 1½ mile from the city hall. From this point a subterranean gallery extends for 1½ mile due west, crossing under the bed of the Olentangy and terminating, as shown on the map, in an inlet-pier on the Scioto river bank. The total length of the gallery, as shown by the profile, is 5,715 feet. It is constructed of open-laid brick below the springing line of the crown, and of brick laid close in cement above said line.

The interior dimensions are 42 inches high by 34 inches wide, the section being oval. The top is protected by palisading, as shown. The whole gallery was excavated, as it was found impracticable to tunnel. The depth below the surface, the dimensions, etc., as well as the character of the material through which the gallery was driven, are shown in the drawing. During the construction of this gallery two pumps were used to remove the water percolating through the soil into the bottom of the trench, and the last day's pumping showed by gauging nearly 2,000,000 gallons supply. One end of this gallery terminates in the water of the river, and a tower rising above the level is furnished with a gate to admit water from the river if necessary; this gate can be operated by electricity from the pump-house. When the works were originally built, it was designed that the water should be derived from the Olentangy river after filtration through the basin represented at A. This basin contained 8,742 feet of filtering surface. The filtering basin A, built on a higher level than B, has its bottom 30 inches below low-water mark in the river. Seven feet below the surface, and on the side next to the river, the basin has a collecting tunnel 18 by 21 inches, which empties into B; from this 14 small porous pipes, all 4½ feet below the surface, radiate beneath the filtering material. This depth of 4½ feet, constituting the filtering material, consists of stones from 2 to 4 inches in diameter at the bottom, decreasing in size to the top, which is composed of a 7-inch layer of fine sand. This basin A is connected with the river directly by a 12-inch valve. The object was to supply any deficiency. The water from A enters the lower basin, B, which is excavated 13 feet below low-water mark. The sides slope 1 to 1, and have a riprap wall of a perpendicular height of 16 feet, above which they slope at an angle of 33°. Area of bottom, 14,294 square feet. Capacity at low-water level in the river, 1,500,000 gallons. The daily filtering capacity of the basin A is 500,000 gallons. On its failure to supply sufficient water, the filtering gallery already described was extended from the inlet-tower on the Olentangy river, underneath the same, to the opposite bank, whence it has been continued each year until it has reached its present length.

From the pump-well in the engine-house water is pumped into the distributing mains by two new-pattern Holly engines constructed in 1870, which are run alternately. Like others of their class, they are operated either as compound condensing or as high-pressure engines. As a usual thing, one cylinder is run at high pressure and the other three condensing. The cylinders are 21 inches in diameter, with a stroke of 30 inches. Engine No. 2 is geared to run at 3½ times the number of revolutions of the pump, while engine No. 1, just mentioned, has its pump-pistons connected directly with the piston-rod of the steam-cylinder. In both engines there are 4 plungers to each pump. The pumps of one set have 27 inches stroke and are 13½ inches in diameter, and the pumps of the other set have a diameter of 12 inches and a stroke of 30 inches. They average from 12 to 30 revolutions per minute, and one or the other is run constantly day and night. The geared engine has three valves in the suction- and three in the discharge-pipe, of the flap-valve type, each 3¾ inches by 10 inches, with a lift of ⅝ of an inch. The other engine has one valve in the suction- and one in the discharge-pipe, each 20½ inches long by 4 inches in diameter, rising $\frac{9}{16}$ of an inch after the manner of a ball-valve. Steam is furnished by two batteries, one containing a pair of multitubular boilers made by the Holly company. One boiler contains fifty-four and the other fifty-six 3¾-inch tubes; the boilers are 60 inches in diameter by 16 to 18 feet length of shell. The other battery contains four double-flue boilers, each 48 inches in diameter and 26 feet long, two of which have 16-inch and two 18-inch flues, and all the boilers are run at a pressure of 70 pounds. The coal used is an inferior grade of bituminous slack, and the evaporative power obtained from both batteries averages 7 pounds of water per pound of coal.

The engines were guaranteed to pump 5,000,000 gallons per day against 60 pounds of water-pressure, and 4,000,000 against 120 pounds pressure, these being, respectively, the domestic and the fire pressure. Connected with each engine is a jet-condenser 3 feet long by 53 inches in diameter, and two air-pumps 16 inches in diameter and 30 inches stroke. For the condensers, cold water is derived by gravity from the river. The cost of the engines from 1871 to 1876, including repairs, was $46,000. The performance of the two engines for the last nine years is given below:

Consumption of slack coal—ashes and cinders deducted	pounds..	29,948,996
Duty—pounds raised 1 foot high with 100 pounds of coal	do....	20,644,546
Water pumped	gallons..	4,405,699,414
Average height to which water was raised	feet....	168.27
Cost of each 1,000 gallons pumped	cents...	4.079
Receipts for each 1,000 gallons pumped	do....	6.606
Net gain on each 1,000 gallons pumped	do....	2.527
Total expenses of operating the works		$179,729 56
Total revenue of the works		$291,047 95
Net earnings		$111,318 39

The original cost of the engines was $40,000.

The cost of the works originally amounted to $700,358 50, divided as shown in the accompanying statement:

Receipts and disbursements for the ten years ending, and including balance on hand, March 31, 1880.

RECEIPTS.

Received from the city on account of construction		$593,819 32
Received from construction of fire-protection lines, etc	$6,840 65	
Received from construction of domestic-supply lines	22,309 17	
Total construction	29,149 82	
Received from sale of office materials	12 00	
Received from water-rents	250,942 29	
Received from meters and repairs of same	10,943 84	
Total receipts from the operations of the works		291,047 95
		884,867 27

DISBURSEMENTS.

For construction of engines, pumps, boilers, buildings, and foundations	$167,932 10	
For construction of fire-protection lines	382,660 81	
For construction of domestic-supply lines	38,024 62	
For construction of filtering galleries, basins, grounds, and levee	83,460 02	
For construction salaries, stationery, and miscellaneous expenses	28,280 95	
Total construction		700,358 50
For cost of pumping	99,982 77	
For care of basins, grounds, gas, and extraordinary repairs	10,413 08	
Total cost of pumping service	110,395 85	
For total cost of hydrant service, including wages, repairs, etc	26,765 94	
For total office expenses, including salaries, etc	29,871 47	
Actual running expenses and repairs	167,033 26	
For return water-rents	751 25	
For meters and repairs of same	11,945 05	
Total operating expenses and repairs		179,729 56
Balance on hand March 31, 1880		4,779 21
		884,867 27

The total net earnings of the works up to March 31, 1880, is $111,318; total operating expenses to same date $179,729; total receipts from operating works to same date, $291,047.

For the year ending March 31, 1880, the cost of maintenance and repairs amounted to $20,669.

For the distribution there are 42 miles of cast-iron pipe, 20, 12, 10, 8, 6, and 4 inches in diameter, the largest being the main from the pump-house. On this system there are 340 Holly patent hydrants, with a few of the Ludlow patent.

Water is supplied to 2,283 water-takers.

An itemized statement of disbursements for a year is annexed, as it may be of value to show the cost of the Holly system in larger cities:

For what purpose.	April, 1879.	May, 1879.	June, 1879.	July, 1879.	August, 1879.	September, 1879.	October, 1879.	November, 1879.	December, 1879.	January, 1880.	February, 1880.	March, 1880.	Totals for the year ending March 31, 1880.
CONSTRUCTION.													
Pumping service.													
Engines, pumps, and boilers	$173 28	$66 84	$2 25	$114 05	....	....	....	....	....	$47 56	....	$12 75	$417 63
Buildings and foundations	....	....	....	....	....	....	....	....	$13 08	....	....	3 50	16 58
Totals	173 28	66 84	2 25	114 05	....	....	....	....	13 08	47 56	....	16 25	434 21
Hydrant service, fire protection.													
Pipe and special castings	283 07	1,445 85	1,065 65	339 94	$2,773 15	$23 67	....	$21 63	21 69	34 05	$116 98	....	6,125 18
Lead, hemp, and pipe-laying	895 89	726 75	1,001 79	528 30	334 83	123 62	....	....	1 40	93 47	20 25	74 35	3,800 65
Fire hydrants and valves	5 10	500 63	39 24	470 39	12 23	2 80	....	30 63	....	....	573 00	70 20	1,704 22
Totals	1,184 06	2,672 73	2,106 68	1,338 63	3,120 21	150 09	....	52 26	23 09	127 52	710 23	144 55	11,630 05
Domestic supply.													
Distributing and service lines	118 08	331 40	89 67	321 60	675 50	101 60	$313 83	226 01	58 50	174 17	72 83	102 63	2,579 88
Incidental.													
Filtering galleries and levee	....	113 85	1 80	534 00	2,476 86	4,465 42	3,241 04	3,253 98	3,287 89	222 04	323 44	3 83	17,924 15
Miscellaneous expenses	....	....	250 00	3 00	28 80	....	....	....	....	15 60	42 50	7 70	347 60
Totals	....	113 85	251 80	537 00	2,505 66	4,465 42	3,241 04	3,253 98	3,287 89	237 64	365 94	11 53	18,271 75
Total construction	1,475 42	3,184 88	2,444 40	2,312 18	6,301 37	4,717 11	3,554 87	3,532 25	3,382 56	586 89	1,149 00	274 96	32,915 89
OPERATING EXPENSES AND REPAIRS.													
Pumping service.													
Wages of employés	635 33	609 33	617 33	616 83	617 33	626 33	608 58	617 33	908 99	326 67	617 33	610 33	7,411 71
Coal	....	753 10	8 05	121 51	....	320 39	53 96	563 38	478 94	7 50	534 00	309 24	3,151 36
Oil and waste	35 35	3 36	52 13	34 57	....	31 48	....	42 33	38 61	54 15	3 91	....	295 89
Ordinary repairs	43 32	26 43	80	35 90	....	6 95	29 65	4 25	6 00	28 27	25 25	8 98	215 80
Cost of pumping	714 00	1,392 31	678 01	808 81	617 33	985 15	692 19	1,227 29	1,432 54	416 59	1,181 09	928 55	11,074 76
Incidental:													
Filtering-basins, grounds, and extra repairs	40 70	38 50	205 14	114 56	14 76	14 50	....	10 50	6 00	72 22	35 36	252 44	804 68
Gas	28 64	12 20	15 76	14 32	....	19 15	....	34 71	18 81	29 77	18 63	....	191 99
Miscellaneous expenses	1 50	1 55	....	143 49	....	2 43	4 70	12 50	15 20	124 88	12 26	....	318 51
Totals	70 84	52 25	220 90	272 37	14 76	36 08	4 70	57 71	40 01	226 87	66 25	252 44	1,315 18
Total cost of pumping service	784 84	1,444 56	899 81	1,081 18	632 09	1,021 23	696 89	1,285 00	1,472 55	643 46	1,247 34	1,180 99	12,389 94
Hydrant service.													
Wages of employés	55 56	55 56	55 56	55 56	55 56	55 56	55 56	38 83	95 49	41 67	83 33	83 33	731 57
Tools and repairs	68 73	28 09	70 77	82 28	24 40	67 25	76 84	65 25	116 16	56 15	62 20	48 23	766 35
Hydrant service repairs	124 29	83 65	126 33	137 84	79 96	122 81	132 40	104 08	211 65	97 82	145 53	131 56	1,497 92
Incidental:													
Extraordinary repairs	86 13	25 94	12 38	5 00	61 07	64 77	88 37	26 00	48 27	....	93 02	53 77	564 72
Miscellaneous expenses	50 35	48 60	108 40	109 40	78 35	96 15	93 92	85 00	57 42	36 85	80 00	71 98	916 42
Totals	136 48	74 54	120 78	114 40	139 42	160 92	182 29	111 00	105 69	36 85	173 02	125 75	1,481 14
Total cost of hydrant service	260 77	158 19	247 11	252 24	219 38	283 73	314 69	215 08	317 34	134 67	318 55	257 31	2,979 06
Office expenses.													
Salaries of officers	341 67	316 67	166 67	166 67	116 67	166 67	266 67	166 67	300 00	83 34	151 67	291 67	2,535 04
Books and stationery	....	4 05	....	20 00	62 00	6 71	50 00	....	....	....	....	....	142 76
Miscellaneous expenses	25 00	25 35	16 00	99 35	494 50	39 12	16 00	16 00	20 00	191 00	22 68	33 12	998 12
Totals	366 67	346 07	182 67	286 02	673 17	212 50	332 67	182 67	320 00	274 34	174 35	324 79	3,675 92
Actual running expenses and repairs.	1,412 28	1,948 82	1,329 59	1,619 44	1,524 64	1,517 46	1,344 25	1,682 75	2,109 89	1,052 47	1,740 24	1,763 09	19,044 92
Incidental:													
Return water-rents	....	1 00	....	25 40	27 00	....	....	....	....	5 00	41 70	9 26	110 26
Meters and repairs of same	741 88	80 79	81 57	93 57	79 21	90 13	111 32	54 03	65 08	12 30	23 32	71 68	1,513 88
Total operating expenses and repairs	2,154 16	2,030 61	1,411 16	1,738 41	1,631 75	1,607 59	1,455 57	1,736 78	2,174 97	1,069 77	1,805 26	1,844 03	20,669 06
Total disbursements for the year	3,629 58	5,224 49	3,855 56	4,050 59	7,933 12	6,324 70	5,010 44	5,269 03	5,557 53	1,656 66	2,954 26	2,118 99	53,584 95

The consumption averages from 2,200,000 to 2,500,000 gallons per day, which is derived entirely from the gallery. The cost of said gallery was $14,000. The intention is to continue its extension in proportion to the increase in water consumption until its limit is reached. This gallery system appears to be eminently applicable to cities located on the western plains, where the water may not be contaminated by surface drainage and impurities.

The following analyses are by H. H. Edgerton, of Fort Wayne, Indiana:

Samples taken from—	Free ammonia.	"Albuminoid ammonia."
Scioto river, muddy	0.04	0.38
Scioto river, settled 24 hours	0.04	0.27
Olentangy river, muddy	0.03	0.36
Water-works water, daily supply	0.13	0.10
Driven well near deep basin B	0.04	0.05
Driven well, center of city	*a* 3.00	0.10

a Probably contaminated with urine.

The works are under the supervision of Frank Doherty, superintendent.

An analysis recently made by Curtis C. Howard, of Columbus, of a sample taken from a city hydrant, gives the following results:

	Grains per gallon.
Carbonate of lime	14.09
Sulphate of lime	0.61
Sulphate of magnesia	9.24
Chloride of sodium	0.41
Silica	Trace.
Organic matter	Trace.
Total	24.35

BURLINGTON, IOWA.

Burlington, containing a population of 19,450, is situated on the west bank of the Mississippi river, and is of considerable commercial importance as a railroad center. It is situated partly on a bluff and partly on ground sharply rising from the river, making the topography very irregular. The streets are laid out rectangularly.

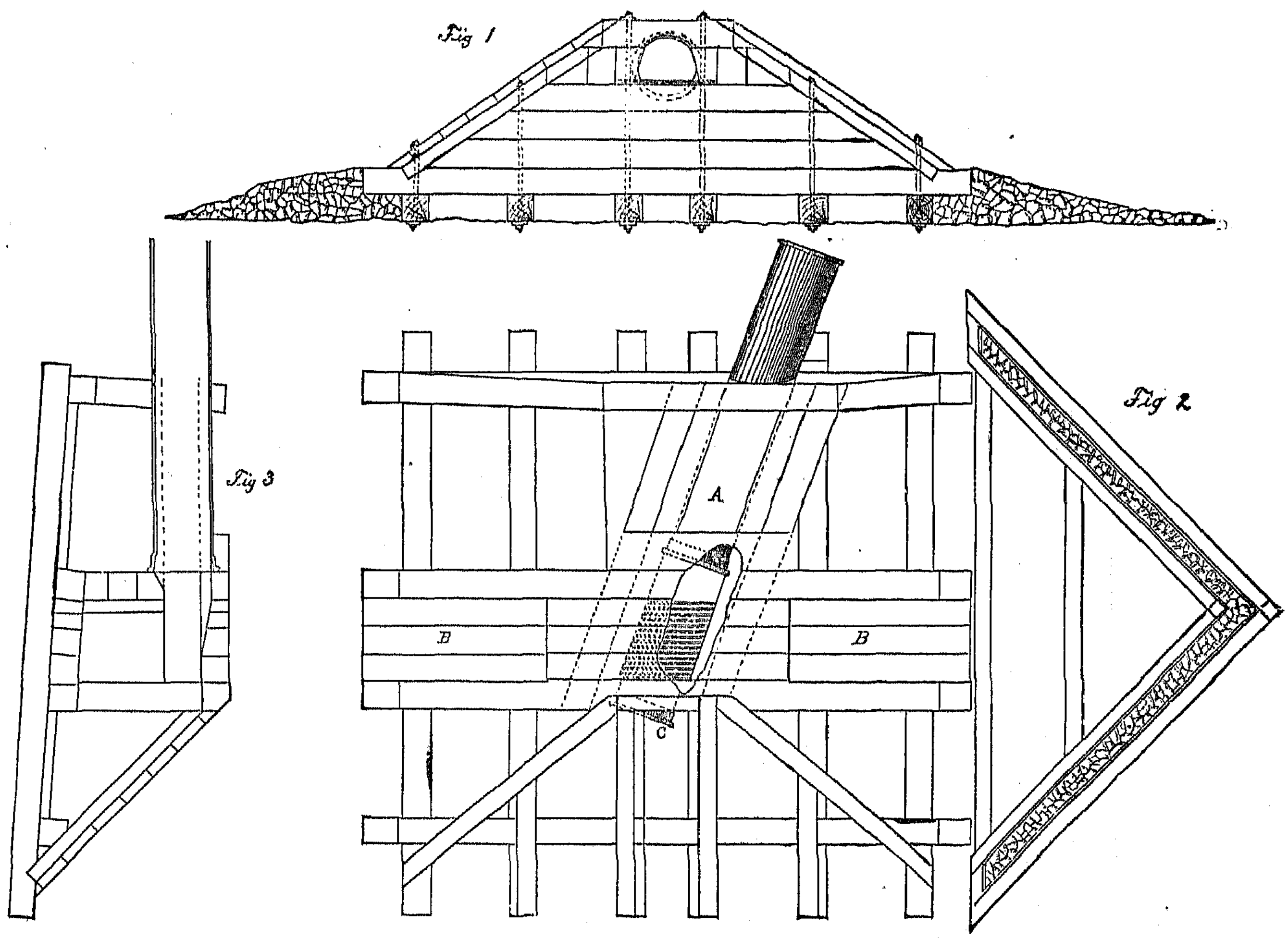
Water was introduced by a private corporation in 1878, and is derived by direct pumping from the Mississippi river. The financial plan followed out in the management of these water-works is worthy of notice. The city guarantees 6 per cent. interest on $200,000 worth of bonds, and levies a tax of 5 mills on all property within 1,000 feet of the mains. It also reserves the privilege of buying the works at the end of 25 years.

The system in use is known as a pure type of the Holly. At a point in the river 250 feet from the shore a crib is sunk, the construction of which is illustrated in the cut on page 51. Fig. 1 shows the end elevation of this crib. It is constructed of a frame of timber held in place by stones. As originally constructed, the inlet-pipe shown at A, Fig. 2, extended only to the side of the sluice-way B, B, but on one occasion the sluice-way became partially obstructed with sand, which the force of the current was unable to remove; it was therefore found necessary to extend it across the sluice-way to C.

The illustrations on page 52 show the filtering gallery. The inlet-pipe is 24 inches in diameter, and extends to the screen-chamber at D, a distance of 375 feet. This chamber is at the eastern end of the gallery, the western end of which is the wall of the pump-house. The gallery is 120 feet long by 20 feet wide by 18 feet deep. It is an arched chamber of masonry, the summit or crown of which is 14 feet below the surface of the ground at the pump-house. The foundations were laid in a blue-clay rock, which softens on exposure to the air. On this a reversed arch of stone, 12 inches thick, was built, and on this, as a flooring, stone blocks 24 inches cube and 8½ feet apart were laid as shown at E, E. Timbers 12 by 16 inches were laid longitudinally of the gallery, as shown at F, F. These serve as a foundation for a flooring, shown at G, constructed of boards 4 inches wide by 2 inches thick and laid 1 inch apart. The filtering material is laid upon this, and consists of a layer of 6 inches of coarse gravel; on this is 6 inches of fine gravel; the next layer is 12 inches of coarse sand; and the top and last layer is 2 feet of fine sand. The surface of the latter is 2 feet below low-water level. The depth of water above the filtering materials varies, therefore, from 2 feet to 21 feet, according to the stage of the river. The sides of the gallery are built of limestone 30 inches thick, surmounted by an arch of 4 feet rise and 24 inches thick.

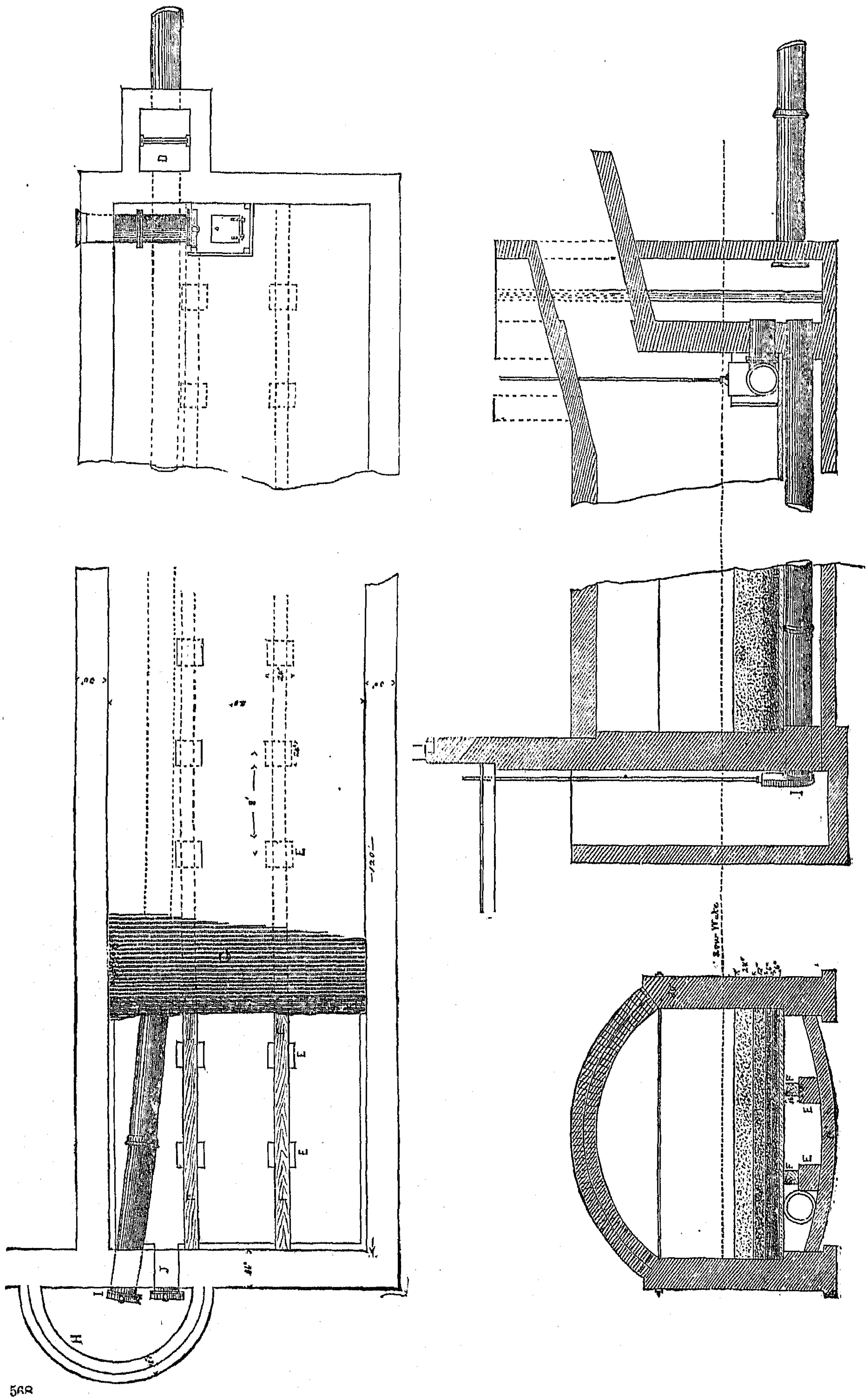
From the western end of the gallery, at H, the pump-well, a 24-inch pipe runs under the flooring of the gallery and connects the screen-chamber with the well direct, enabling the water to be taken direct from the river without passing through the filtering material. This can be closed by a gate at I. A short pipe at J serves to admit the filtered water into the pump-well, and is also controlled by a gate. Every three months a layer of from 4 to 6 inches of slime is cleaned from the surface of the sand.

From the pump-well the water is drawn into the suction-pipe of the pumping-engine and forced into the mains. This engine, built by the Holly company in 1878, is known as the new-patent Holly, having four piston-plungers, each 10 inches diameter, with 27 inches stroke (see illustration on page 53). The engine may be run as non-condensing, condensing, or compound, the latter condition being when exhaust-steam from one or more of the cylinders is admitted to the remaining cylinders. The diameter of the steam-cylinders is 19 inches, the stroke being 27 inches, with 7 inches clearance at the ends of the pump-cylinders. Steam is distributed by a slide-valve, as shown in the cut, the cut-off being a puppet-valve operated by a solid revolving cam. The condenser is 5 feet high and 4½ by 2 feet, of the surface pattern. The water enters through a 6-inch inlet at the top, falling upon a set of inclined shelves, and flowing out through a pipe at the bottom. The steam enters at one side just below the middle. There are two air-pumps 18 inches diameter by 24 inches stroke. The capacity of the engine is 3,000,000 gallons per 24 hours. The trial showed a duty of 71,514,000 foot-pounds, 60,000,000 being guaranteed. The average speed is from 12 to 15 revolutions per minute. During 1880 this engine was stopped for repairs only $1\frac{1}{5}$ minute. There are 16 leather-faced brass disk valves—8 suction and 8 discharge—in each pump-cylinder, with a diameter of 6 inches and a lift of $\frac{3}{8}$ inch. Although capable of a high duty, the daily average of this engine is only about 36,260,000 foot-pounds.

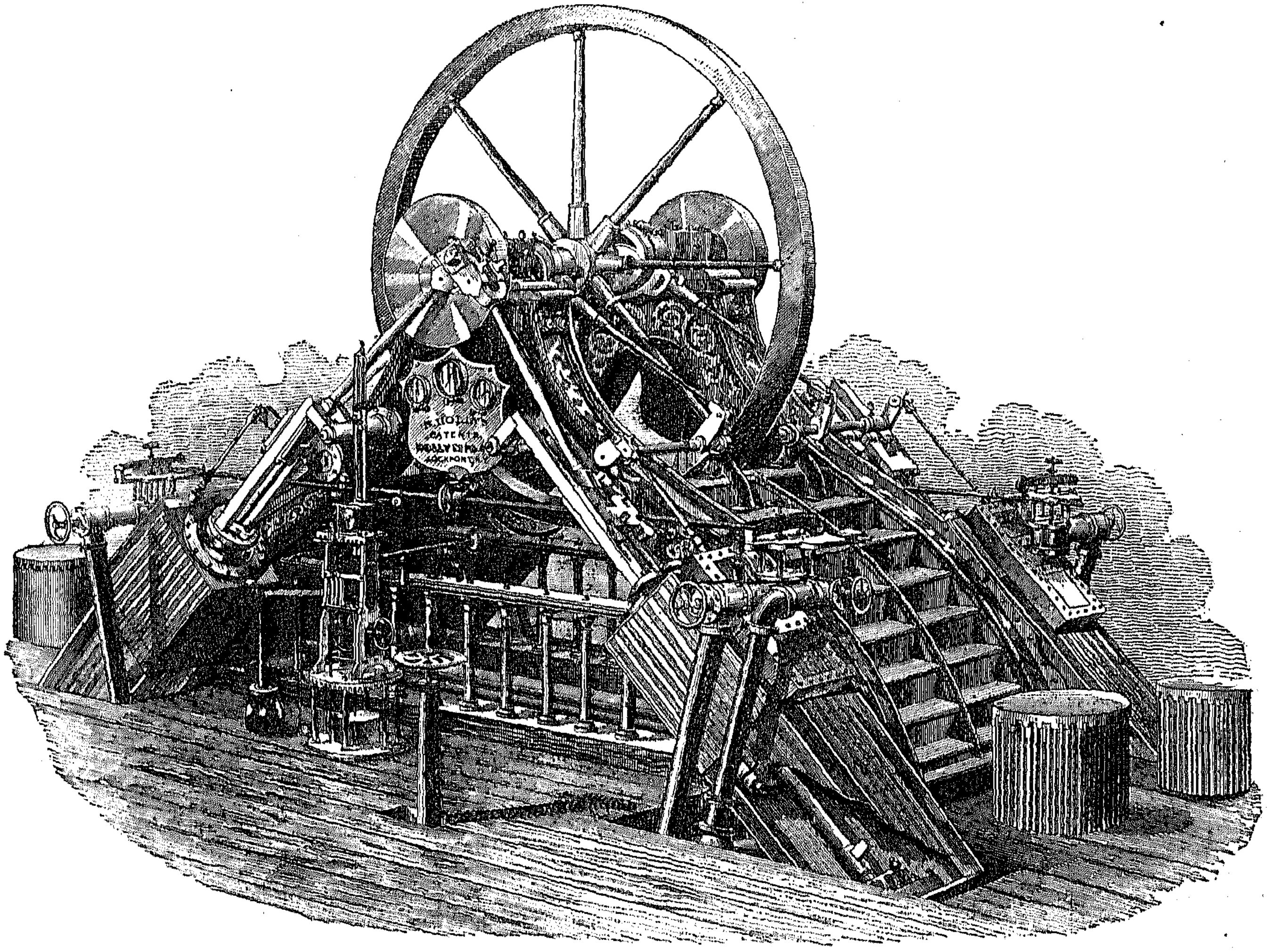


The ordinary domestic pressure is 85 pounds at night and 90 pounds during the day. On the outbreak of a fire the pressure is increased to 120 pounds, and can be raised to 175 pounds per square inch. Occasion arising, this operation occupied less than two minutes from the striking of the alarm.

Steam is derived from a battery of three multitubular boilers made by the Holly company, and 16 feet long by 5 feet in diameter, containing fifty-eight 4-inch tubes in each. From the bridge of one boiler to the space at the back of the next, between the brick setting and the ends of the flues, a 24-inch iron pipe passes. The pressure averages 60 pounds, and using a coal-slack from Illinois, an evaporation of $5\frac{1}{2}$ pounds per pound of coal is produced. On a duty trial this can be increased to 9 pounds per pound of coal.



The work at present performed by this engine consists in pumping daily about 590,000 gallons for the use of 811 water-takers. A system of mains of cast iron $1\frac{4100}{5280}$ mile long serves to distribute it. In addition there is $1\frac{4246}{5280}$ mile of wrought-iron pipe, varying from $\frac{3}{4}$ to $1\frac{1}{2}$ inch diameter, used as service-mains. The mains are of 24, 16, 12, 10, 8, 6, and 4 inches diameter, and Holly's patent hydrants to the number of 202 are attached to them.



The cost of these works was to have amounted to $200,000 by the contract, but they were finished completely for $185,000. The annual cost of maintenance and repairs, including salaries, etc., is, for 1880, $6,000.

About 100 Crown meters are in use, giving satisfaction.

No analysis of the river water has ever been made as taken from this point. The works are managed by Mr. Ira A Holly, superintendent.

Burlington water-works—Record of engines and pumps,

Date.	Day.	Running time.	Number of boiler.	Steam pressure.	Inches vacuum.	Pressure maintained for domestic service.	Register reading of revolutions.	Revolutions of engines for 24 hours.	Total pump revolutions per 24 hours.	Number of pumps running.	Coal burned for 24 hours.	Kind of coal burned.	Water pumped in 24 hours.	Duty—pounds raised one foot high with 100 pounds of coal.	Time of fire-alarm received.
							a 163, 595								
		Hrs.		*Lbs.*		*Lbs.*					*Pounds.*		*Gallons.*		
1	Sunday	24	2	60	27½	90	180, 330	16, 735	33, 470	2	3, 443	Slack and nut	692, 460	33, 512, 384	....
2	Monday	24	2	60	27½	90	198, 500	18, 170	46, 275	$\frac{2}{3}$	4, 737	....do	832, 950	33, 824, 416	....
3	Tuesday	24	2	60	27½	90	217, 542	19, 042	46, 080	$\frac{2}{3}$	4, 677	....do	829, 440	34, 113, 979	....
4	Wednesday	24	2	60	27½	90	236, 300	18, 758	46, 669	$\frac{2}{3}$	4, 715	....do	840, 012	34, 271, 575	....
5	Thursday	24	2	60	27½	90	255, 000	18, 700	45, 540	$\frac{2}{3}$	4, 404	....do	819, 828	35, 965, 206	....
6	Friday	24	2	60	27½	90	275, 275	20, 185	50, 046	$\frac{2}{3}$	4, 826	....do	917, 028	36, 711, 522	....
7	Saturday	24	2	60	27½	90	295, 121	19, 845	49, 099	$\frac{2}{3}$	4, 938	....do	899, 082	35, 009, 421	....
8	Sunday	24	2	60	27½	90	313, 523	18, 402	36, 804	2	3, 545	....do	692, 472	36, 258, 410	....
9	Monday	24	2	60	27½	90	332, 572	19, 049	48, 063	$\frac{2}{3}$	4, 862	....do	865, 134	34, 527, 067	....
10	Tuesday	24	2	60	27½	90	351, 405	18, 833	47, 070	$\frac{2}{3}$	4, 352	....do	858, 168	38, 202, 010	....
11	Wednesday	24	2	60	27½	90	370, 840	19, 435	49, 883	$\frac{2}{3}$	5, 423	....do	897, 894	32, 127, 485	....
12	Thursday	24	3	60	27½	90	390, 250	19, 410	48, 215	$\frac{2}{3}$	4, 083	....do	867, 870	35, 960, 173	....
13	Friday	24	3	60	27½	90	410, 225	19, 975	51, 404	$\frac{2}{3}$	4, 943	....do	925, 272	36, 164, 869	....
14	Saturday	24	3	60	27½	60	429, 800	19, 575	50, 009	$\frac{2}{3}$	4, 736	....do	910, 962	37, 101, 700	....
15	Sunday	24	3	60	27	60	445, 851	16, 051	38, 998	$\frac{2}{3}$	3, 814	....do	701, 964	35, 558, 323	....
16	Monday	24	3	60	27	90	466, 050	20, 199	52, 848	$\frac{2}{3}$	4, 980	....do	951, 264	36, 904, 458	....
17	Tuesday	24	3	60	27	90	485, 745	19, 695	51, 404	$\frac{2}{3}$	4, 713	....do	925, 272	37, 020, 673	....
18	Wednesday	24	3	60	27	90	506, 107	20, 362	52, 888	$\frac{2}{3}$	4, 880	....do	951, 984	37, 080, 202	....
19	Thursday	24	3	60	27½	90	526, 195	20, 088	53, 531	$\frac{2}{3}$	4, 984	....do	963, 558	37, 351, 405	....
20	Friday	24	3	60	27½	90	548, 084	21, 889	56, 546	$\frac{2}{3}$	5, 430	....do	1, 017, 828	36, 214, 432	....
21	Saturday	24	3	60	27½	90	570, 720	22, 636	60, 055	$\frac{2}{3}$	5, 709	....do	1, 080, 900	36, 014, 859	....
22	Sunday	24	3	60	27½	90	589, 685	18, 965	46, 128	$\frac{2}{3}$	4, 581	....do	830, 304	35, 017, 405	....
23	Monday	24	3	60	27½	90	609, 771	20, 086	52, 500	$\frac{2}{3}$	5, 451	....do	946, 020	33, 551, 088	11. 40 p. m.
24	Tuesday	24	3	60	27½	90	630, 221	20, 450	53, 928	$\frac{2}{3}$	5, 269	....do	950, 904	35, 107, 087	....
25	Wednesday	24	3	60	27½	90	652, 030	21, 809	59, 078	$\frac{2}{3}$	5, 831	....do	1, 063, 404	35, 387, 225	....
26	Thursday	24	3	60	27½	90	675, 541	23, 511	64, 683	$\frac{2}{3}$	6, 038	....do	1, 164, 204	37, 410, 208	....
27	Friday	24	3	60	27½	90	699, 000	23, 459	65, 221	$\frac{2}{3}$	5, 990	....do	1, 173, 978	38, 020, 831	....
28	Saturday	24	3	60	27½	90	722, 695	33, 695	65, 212	$\frac{2}{3}$	5, 986	....do	1, 173, 816	38, 049, 992	....
29	Sunday	24	3	60	27½	90	742, 951	20, 256	51, 206	$\frac{2}{3}$	5, 336	....do	923, 328	33, 576, 102	....
30	Monday	24	2	60	27½	90	765, 685	22, 734	61, 635	$\frac{2}{3}$	5, 716	....do	1, 109, 430	37, 824, 083	....
31	Tuesday	24	2	60	27½	90	787, 355	21, 670	58, 710	$\frac{2}{3}$	5, 880	....do	1, 056, 780	35, 024, 708	....
	Totals and averages.	744	......	......	......	......	....	623, 760	1, 595, 790	......	154, 962	....	28, 724, 220	35, 812, 130	....

a State of register on April 30, 1881.

service, and duty, for the month ending May 31, 1881.

Water-pressure during fire.	End of fire-pressure.	Revolutions of engines during fire.	Lift of pumps.	Height of column of water.	Fuel consumed for each 1,000,000 gallons pumped.	Cost of fuel consumed for each 1,000,000 gallons pumped.	Meter reading of feed-water.	Water evaporated per each pound of fuel consumed.	Machine-oil used.	Cylinder-oil used.	Ashes and cinders left.	Waste and rags used.	Remarks.
							a 259,403						
			Feet.	*Feet.*	*Pounds.*			*Pounds.*	*Galls.*	*Galls.*	*Pounds.*	*Pounds.*	
......	....	......	21.50	228	5,714	$6 14	259,073	6.4	....	....	517	....	Slack and nut coal costs $2 15 per ton.
......	....	......	22.00	229	5,687	6 11	260,093	4.5	....	....	616	....	
......	....	......	22.20	229	5,638	6 06	260,393	4.6	....	....	618	....	
......	....	......	22.60	229	5,612	6 03	260,693	4.6	....	....	636	....	
......	....	......	22.11	230	5,371	5 77	260,993	4.9	....	....	597	....	
......	....	......	23.10	230	5,262	6 56	261,293	4.4	....	....	607	....	
......	....	......	23.50	230	5,486	5 89	261,593	4.4	....	....	636	....	
......	....	......	23.80	231	5,351	5 75	261,893	6.2	....	....	507	....	
......	....	......	23.11	231	5,619	6 04	262,193	4.4	....	....	579	....	
......	....	......	24.00	231	5,071	5 45	262,493	4.9	....	....	562	....	
......	....	......	24.00	231	6,030	6 49	262,793	3.6	....	....	182	....	Changed boilers.
......	....	......	23.00	231	5,305	5 70	263,093	4.6	....	....	600	....	
......	....	......	23.00	230	5,342	5 74	263,393	4.4	....	....	655	....	
......	....	......	22.10	230	5,198	5 58	263,693	5.3	....	....	1,200	....	
......	....	......	22.60	230	5,433	5 84	263,993	5.7	....	....	545	....	
......	....	......	22.60	230	5,235	5 62	264,441	6.5	....	....	642	....	
......	....	......	22.60	230	5,093	5 47	264,710	4.1	....	....	620	....	
......	....	......	22.60	230	5,126	5 51	264,820	1.6	....	....	617	....	Packed L. F. pump-piston.
......	....	......	22.20	230	5,172	5 55	265,170	5.1	....	....	602	....	
......	....	......	22.00	230	5,324	5 73	265,520	4.7	....	....	776	....	Packed L. B. pump-piston.
......	....	......	21.80	230	5,364	5 76	265,870	4.4	....	....	705	....	
......	....	....	22.50	230	5,517	5 93	266,220	5.5	....	....	583	....	Fixing leak corner Boundary and Jefferson streets.
130	11.50 p. m.	120	22.90	230	5,758	6 18	266,300	2.2	....	....	716	....	Fire; small frame on Jefferson street, between Eighth and Boundary streets.
......	....	......	23.50	230	5,489	5 90	266,790	5.4	....	....	665	....	
......	....	......	23.10	231	5,483	5 89	267,190	4.9	....	....	733	....	
......	....	......	24.00	231	5,185	5 57	267,590	4.9	....	....	920	....	Thermometer 88° in the shade.
......	....	......	24.40	231	5,102	5 48	267,990	4.8	....	....	811	....	Thermometer 90° in the shade.
......	....	......	24.40	231	5,099	5 48	268,390	5.0	....	....	978	....	Thermometer 94° in the shade.
......	....	......	24.50	231	5,779	6 21	268,790	4.8	....	....	193	....	Changed boilers.
......	....	......	24.10	232	5,152	5 53	269,190	5.1	....	....	824	....	
......	....	......	25.00	232	5,564	5 98	269,590	5.5	....	....	1,332	....	
......	....	......	....	230	5,394	5 79	*b* 10,097	4.7	2	4	20,924	20	

a State of meter on April 30, 1881. *b* Cubic feet.

Average amount of water pumped per 24 hours, in gallons, 926,587.7; average amount of coal used per 24 hours, in pounds, 4,998.7; total cost of each 1,000,000 gallons pumped, $69.37 (including construction account); average revolutions per minute of engine, 13.9; pounds of water raised 1 foot high for each pound of coal consumed, 358,110; pounds of water raised 230 feet high for each pound of coal consumed, 1,557.

IRA A. HOLLY,
Superintendent of Water Works.

PEORIA, ILLINOIS.

Peoria contains a population of 29,259, and is situated on the west bank of the Illinois river, 192 miles above its mouth. Its site is an elevated plateau, about 2 miles square, one side sloping down toward the river. The streets are laid out rectangularly.

Water was introduced in 1869 from the Illinois river by pumping direct into the mains; the works are under municipal control. The water is taken from the river, at a point 2 miles northeast of the court-house, by an iron pipe 24 inches in diameter and 300 feet long, the end resting in the channel and protected by a screen. This pipe enters a basin 86 feet long, 20 feet wide, by 32 feet deep, situated alongside the pump-house about 600 feet from the river; this was originally intended for a filtering basin. The basin has perpendicular walls, and the bottom is grouted, cemented, and planked. The pump-well, located 10 feet from it in the engine-house, is 14 feet in diameter and 23 feet deep below the floor, and is connected with it by a masonry conduit 10 feet long. One wall of the engine-house is built upon the south wall of the basin, and the flooring is 9 feet above the level of the top of the basin. The basin was never supplied with filtering material. The pump-house of brick contains four sets of pumping-engines, two Worthington duplex, built in 1881, one Cameron "special", built in 1875 at the same time with a Dean duplex. A set of Holly pumps, operated by a Holly 2-cylinder fly-wheel-engine, built in 1869, was operated five years, and was finally removed in 1879, the whole having cost $48,000.

The Worthington engines have steam-cylinders 25 inches in diameter, pump-cylinders 14 inches in diameter, with a stroke of 24 inches. There are twelve inlet and twelve outlet rubber-disk valves 5 inches in diameter, resting on a sort of gridiron seat and lifting $1\frac{1}{4}$ inch. The jet-condenser used is $4\frac{1}{2}$ by $1\frac{1}{2}$ feet, and contains three perforated plates 1 foot apart, with a water-inlet at the top $2\frac{1}{2}$ inches in diameter and the steam-pipe 6 inches in diameter for the two cylinders. The air-pumps are 18 inches in diameter with 12 inches stroke. The pumps are run at about 18 double strokes per minute.

The Dean duplex consists of two pumps coupled to the same shaft with two fly-wheels. The steam-cylinders are 24 inches in diameter with 20 inches stroke, the pumps being 14 inches in diameter. They are operated at high pressure. There are two inlet- and two outlet-valves at the end of each cylinder, the pumps being double-acting; they are rubber-disk valves $7\frac{1}{2}$ inches in diameter, with a spiral spring, allowing a lift of 1 inch. The suction- and discharge-pipes are 10 inches in diameter, and the pumps are operated at from 18 to 30 revolutions per minute.

The Cameron "special" is a non-condensing, direct, double-acting pump, with steam-cylinder 24 inches and pump-cylinder 12 inches in diameter, and a stroke of 3 feet, operated at from 4 to 6 revolutions per minute, and contains two inlet and two discharge rubber-faced brass disk valves, 9 inches in diameter with 1 inch lift, with spiral springs. The Dean pump cost $6,000, the Cameron $2,500, and the Worthington $17,800.

There are two batteries of two multitubular boilers each, 16 feet long by 56 inches diameter of shell, containing 50 $3\frac{3}{4}$-inch tubes in each, burning soft coal from local mines at a pressure of 90 pounds. There have never been any duty trials nor tests of evaporation. The original boilers cost $3,600, and a new set recently erected cost $4,300. The capacity of the Dean pump for 24 hours is 2,500,000 gallons; of the Cameron, 1,750,000 gallons; and of the two Worthington, 5,000,000 gallons.

The pressure at the pump-house for domestic purposes is from 55 to 60 pounds, with the exception of a single line of 10-inch main which supplies the "bluff" or high parts of the city, on which line the pressure is 90 pounds. In case of fire this pressure is increased to 150 pounds, and on the main service from 110 to 140 pounds. The city consumption averages 2,000,000 gallons per day distributed to 2,190 takers, through 43 miles of cast-iron mains 4, 6, 8, 10, 12, and 16 inches in diameter, with 263 hydrants, chiefly Holly's patent, with a few of the Matthews patent. The first cost of the water-works was $450,000. The annual expense of maintenance and repairs amounts to $14,000.

The water taken from the river is exceedingly impure, with a disagreeable odor during a large part of the year. In the winter when the river is frozen over the odor seems to be increased, and in the boiler-room any escaping steam develops this to an unbearable degree. It is ascribed to the pollution of the river by Chicago sewerage. The present superintendent is Mr. T. J. Kelley, and the mechanical engineer, Mr. David Nicol.